A SIMULATION MODEL FOR STUDYING EFFECTS OF POLLUTION AND FRESHWATER INFLOW ON SECONDARY PRODUCTIVITY IN AN ECOSYSTEM

by

ROBERT WARD JOHNSON

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A thesis submitted to the Graduate Faculty of
North Carolina State University at Raleigh
in partial fulfillment of the
requirements for the Degree of
Doctor of Philosophy

DEPARTMENT OF MARINE SCIENCES

RALEIGH

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ABSTRACT

JOHNSON, ROBERT WARD. A Simulation Model for Studying Effects of Pollution and Freshwater Inflow on Secondary Productivity in an Ecosystem.

Operations research methodology is used to develop a mathematical model of the Galveston Bay, Texas, ecosystem. Secondary productivity, measured by harvestable species (such as fish, crabs, and shrimp), is evaluated in terms of man-related and controllable factors, such as quantity and quality of inlet fresh water and pollutants. The simulation type model uses information from an existing physical parameters model as well as pertinent biological measurements.

One of the purposes of the model is to provide predictive information of value to those responsible for estuarine management. Results are of major benefit in pollution control and fisheries management in estuarine systems, particularly those which have migrating species, which include fish (menhaden, trout, bass, croaker for example), shrimp, and crabs. Another objective of the study is to identify those biological, chemical, and physical parameters that should be measured in order to develop models for similar ecosystems.

The Galveston Bay, Texas, is a highly productive temperate-zone ecosystem that has been subjected to man-related stresses. There are extensive hisotrical biological data and analyses available as well as chemical and physical parameters models of the ecosystem. This in-depth information is highly desirable for the modeling of an ecosystem.

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BIOGRAPHY

Robert W. Johnson was born [redacted]. He received his elementary and secondary education in Hampton, graduating from Hampton High School in 1946.

He received the Bachelor of Science degree in Mechanical Engineering from the Virginia Polytechnic Institute in 1950. From that time until September 1953, he was in the U.S. Army and worked as a design engineer for the Philco Corporation. In June 1954, he received a Master of Science degree in Mechanical Engineering from the Pennsylvania State University. After three years at E. I. du Pont Co., Wilmington, Delaware, and six years at the Carrier Air Conditioning Company, Syracuse, N. Y., he came to NASA, Langley Research Center in 1963. His research work has included integrated manned life support systems and, currently, investigations for the application of remote sensing to the marine environment.

The author is married to the former Miss Gretchen Patricia Showalter, and they have a son, Aric, and three daughters--Melissa, Janna, and Lutitia.

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This study was conducted under a graduate leave program supported by the National Aeronautics and Space Administration. In addition, administrative and technical support were provided by the Langley Research Center for computer analyses, typing, reproduction, and other necessary activities.

Drs. B. J. Copeland and G. E. Bennington, my committee co-chairmen deserve my special appreciation for their positive support and guidance during my graduate study program and preparation of this document. Dr. L. J. Langfelder and Professor R. W. Llewellyn of my committee also made significant contributions during this period.

Finally, without the support and confidence of my wife, Gretchen, and children, Aric, Melissa, Janna, and Lutitia this effort would not have been started, much less completed.

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INTRODUCTION

Estuarine systems, due to their unique locations at the interface of rivers and seas, are under heavy user and development pressures. These highly competitive forces include economic, political, social, and recreational potentials and place high priority on certain estuarine characteristics that are important for man-related uses for commercial (manufacturing and shipping), residential, and recreational purposes, as well as biological productivity. Concurrent incompatible uses in close proximity lead to "pollution" conditions; that is, a user benefit suffering due to another activity.

Generally, the concept of pollution involves a man-related activity that disturbs the "natural" system; or more specifically, the discharge of nutrients or other energy (heated water) and/or toxic materials. Other forms of pollution (or something that perturbates the system) involve flow characteristics of the system, consequently affecting the environmental conditions such as temperature and salinity. These may be due to dredging in the estuary, or upstream river flow changes such as damming and impoundments. These factors affect the estuarine system, whether or not combined with nutrient or toxic discharges (Gunter 1950, 1961; Gunter, Christmas and Kellibrew 1964; Copeland 1966; Cooper 1970; Copeland and Bechtel 1971).

Each of the users which may potentially benefit from the characteristics of an estuarine system should have an input and consequently some priority to obtain estuarine benefits. In any event, use of

estuarine systems is the result of management, whether formal or informal. As competive uses grow it will be necessary to apply a more formalized management system, which requires analyses that will provide information so the best decisions may be made. This general approach is within the scope of the systems analysis (Van Dyne 1969; Dale 1970; E. P. Odum 1971; Patten 1971), and requires that quantitative information be available on which to base the analysis and subsequent inputs to management, who make the decisions.

One of the areas currently notable for the lack of quantitative information to use as inputs to the decision-making process is associated with the biological complex of an estuary and the resultant changes in the system as various exogenous changes are made, whether natural or man-caused.

Notable and significant groundwork, some theoretical, some parametric, has been initiated by Patten (1959), H. T. Odum (1967) and Paulik (1971). Computerized models have been developed for certain specific cases, such as the salmon industry, by Paulik (1967).

On an ecosystem conceptual basis, Watt (1966, 1968), Van Dyne (1969), Kowal (1971) and Patten (1971) have developed field, insect, and aquatic ecosystem models to demonstrate systems analysis as an applicable quantitative tool. Williams (1971), in his computer simulation of Linderman's (1942) data from Cedar Bog Lake, indicates the lack of data available for current modeling procedures.

One of the areas probably receiving too little attention in past modeling efforts have been the necessary steps of following through on

the modeling process by making predictions (using an initial model), gathering current data, comparing the predicted to observed data, making any necessary model corrections, then repeating the process until suitable agreement is obtained (Watt 1968). Since a system reaction to exogenous changes should be the same, historical or new data may be used in the above modeling processes.

Fisheries studies in estuarine systems have concentrated on: 1) migration (Gunter 1950; Copeland 1965; Copeland and Fruh 1970), 2) feeding and food availability (Darnell 1958, 1959, 1961; Heald 1971; W. E. Odum 1971), and 3) pollution effects on respiration and growth (Wohlschlag 1972). Results of these studies provide qualitative and short term cause and effect analyses within an estuary. In addition, the concept of diversity index (Copeland and Fruh 1970; Copeland and Bechtel 1971), and its relation to pollution have aided in the quantitative assessment of pollution on the biological communities.

International and open sea fisheries studies have been concerned with growth and population dynamics of the fish of commercial interest. Pertinent information on growth characteristics are developed by von Bertalanffy (1938), Parker and Larkin (1959), Ivlev (1966), Ursin (1967), and Nickolski (1969). Most of these concepts are based on theoretical as well as sampling and commercial catch studies, and consequently have broad application.

Environmental stresses are commonplace in natural systems and are a large factor in determining communities and populations (Slobodkin 1960, 1962, 1967; Margalef 1963, 1968; Odum, Copeland, and McMahon 1969).

Estuarine systems, particularly those in the temperate regions, have seasonal stress patterns that dominate the natural biological communities through control of these environmental stress factors. The seasonal peak of energy flow down the rivers in the spring leads to the well-known migrations of commercially important fish, shrimp, and crabs to the estuaries where not only is there bountious food, but essentially predator-free nursery areas. Rapid growths occur, followed by outward migrations due to organism physiological preference and environmental changes of temperature and salinity (Copeland 1965; Copeland and Truitt 1966).

In recent years, as industrial and population growths have increased along rivers and estuarine areas, a new set of stresses have been levied on the biological populations. An in-depth study of the effects of thermal, nutrient, and toxic effluents was reported by Brett (1957) on the rivers of British Columbia. The basic approach was to evaluate the effluents as causes of stress (with stress being defined as a state under which chances for survival are reduced) taking into account the entire life span of the organism as well as short-term effects. Cronin and Flemer (1967) also evaluated the effects of pollution on energy transfer in coastal environments and include chemical growth inhibitors as a significant factor.

Toxic pollution causes stress conditions that are indiscriminate in character; i.e., affects each member of the group (as opposed to discriminate stress which affects individuals single, but not the group

as a whole, like predation, individual parasitism, trapping, etc.) and may be lethal, limiting, inhibiting, or loading (Brett 1957). These three latter stress conditions and their effects on growth, survival, metabolism, and population dynamics have also been investigated by Steed and Copeland (1967), Wohlschlag and Cameron (1967), Mount (1968), Wohlschlag, Cameron and Cech (1968), Copeland and Wohlschlag (1971), Kloth and Wohlschlag (1972), and Wohlschlag (1972). There are many factors associated with sublethal stress conditions that are still not clearly understood, but it is evident that the decreased metabolism due to toxic and temperature effects (Warren and Davis 1966; Copeland and Wohlschlag 1971; Wohlschlag 1972) leads to decreased growth rates and subsequent effects on the ability of species to compete and survive.

It is the purpose of this effort to develop a biologically sound computerized simulation model of the biological energy flow through an estuarine system, specifically the Galveston Bay, Texas. Fish, shrimp, and other organism growth characteristics will be based on logistic growth patterns as recommended by von Bertalanffy (1938), Ursin (1967), and Patten (1971), with limiting conditions imposed by food supply, migrations, and stresses (toxic or environmental). Exogenous inputs will include "natural" variations such as seasonal immigration and emigration, salinity, and food supply patterns. In addition, man-controllable (through management) factors related to river freshwater flow manipulation and pollution effluent will be considered. System outputs will be biomass levels for the organisms (fish, shrimp, etc.)

in the bay and emigration, which will be taken as a measure of the productivity of the bay.

Validation of the model will be approached by 1) comparing organism food consumption to that available in the estuary and 2) comparing predicted results from the model to results obtained from analogous field studies. In the latter case the model is used to investigate the effects on fisheries productivity due to changes of pollution and/or further decrease in freshwater (e.g., due to damming of the Trinity River).

A further objective of this model and analysis effort will be to identify areas of future research and/or data needed for effective and efficient pollution control and management of estuarine systems.

THE GALVESTON BAY

Physical, Chemical, and Biological Characteristics

Physical, chemical, and biological characteristics of the Galveston Bay, Texas, estuary have been studied by Cooper (1970), Copeland and Fruh (1970), and Armstrong and Hinson (1973). Major effects in the system are due to changes in freshwater inflow and pollution inputs. These affect the primary characteristics of salinity and total nitrogen (which is used as a measure of pollution load in this study). Average annual salinity and total nitrogen distributions for 1969 (Copeland and Fruh, 1970) are shown in figures 1 and 2, respectively.

Copeland and Fruh (1970) reported percent sources of water at each of their sampling stations in Galveston Bay, obtained from a low-flow conservative model. Source water fractions and yearly average salinity and total nitrogen values are listed in table I. Salinity and total nitrogen values for subsequent years were determined from source water changes on a station by station basis. Estuary levels were determined by arithmetically averaging the station values.

Armstrong and Hinson (1973) investigated freshwater inflow quantities and waste discharges from the major tributaries of the Galveston Bay. These values were grouped into the same sources as used by Copeland and Fruh (1970) for each of the stations for subsequent analysis of changes. Ten year water and three year (1969-71) waste average discharge rates were

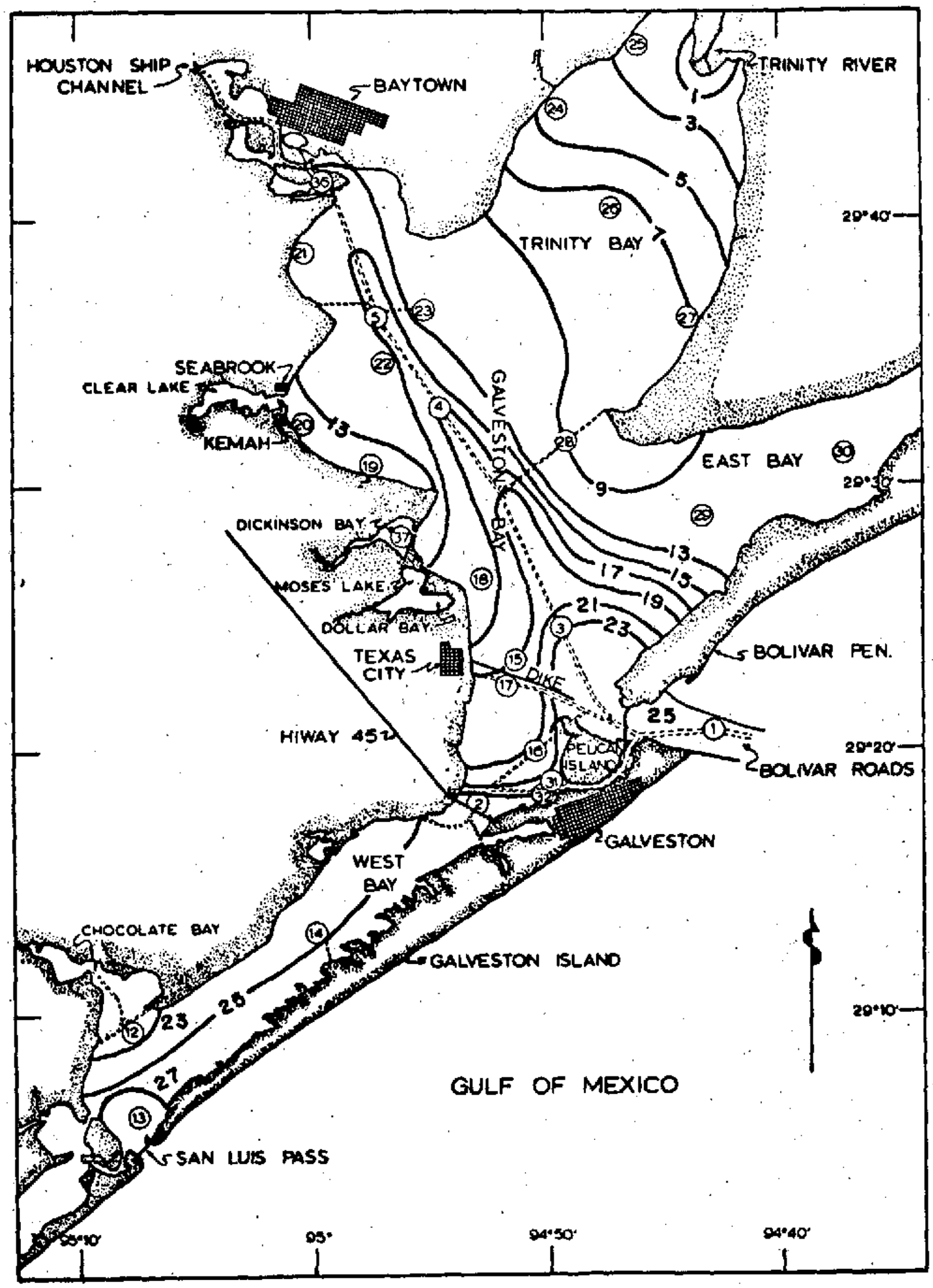

Figure 1.- Isohalines for the Galveston Bay system plotted from mean annual salinity (ppt) at each station. Data from collection cruises during February, April, July and October 1969 (from Copeland and Fruh, 1970).

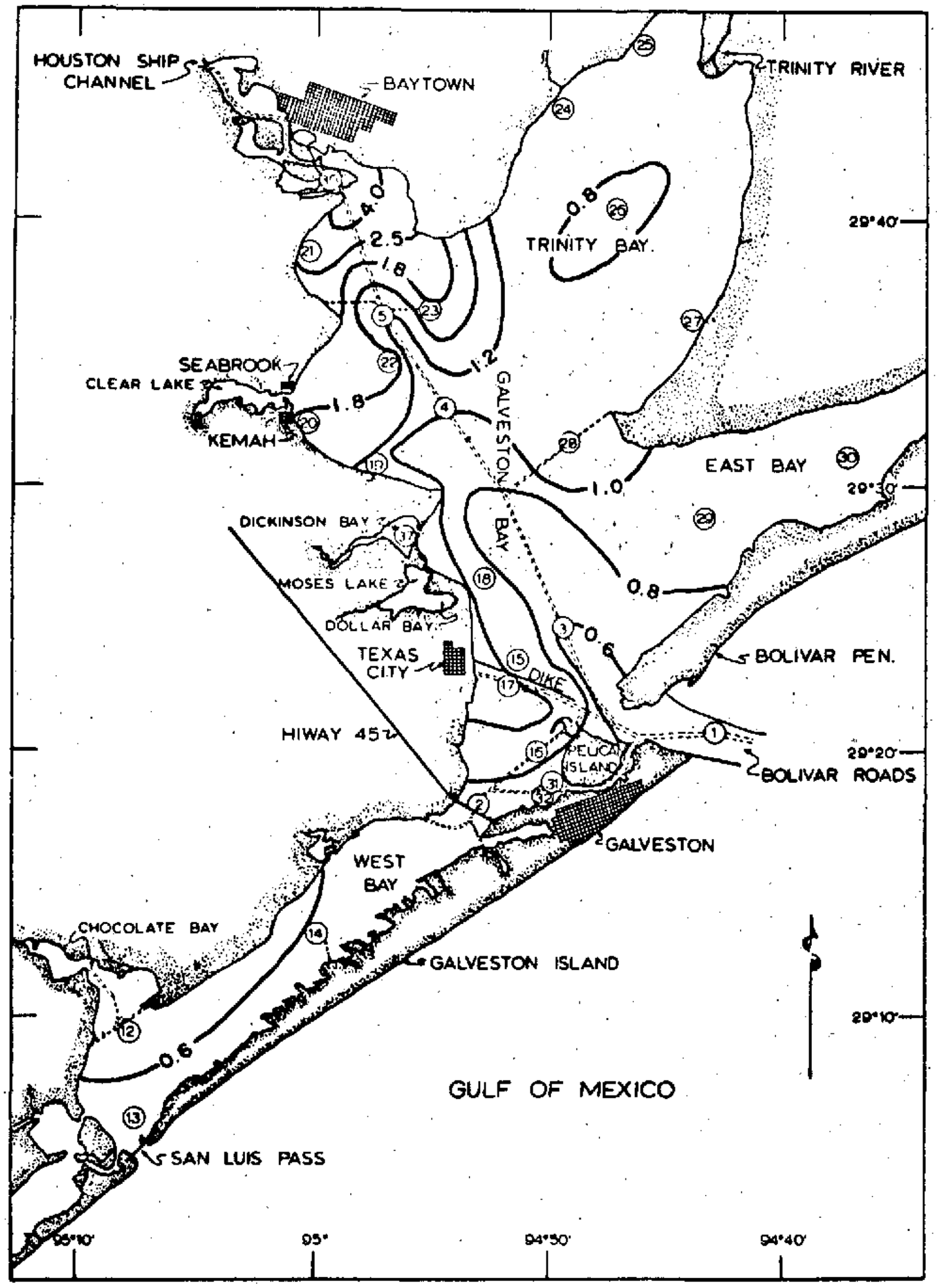

Figure 2.- Mean annual concentration gradients of total nitrogen (mg/l) for the Galveston Bay system. Data taken from monthly values of the 1969 Bay Sampling Program (from Copeland and Fruh, 1970).

Table I: Galveston Bay station water sources and yearly average salinity (ppt) and total nitrogen (mg/ℓ) from Copeland and Fruh, 1970.

Station	Source Water				Sal, ppt	T NIT, mg/l
	Bol. Roads	T. River	HSC	Other		
1.00	.74	.07	.14	.05	27.00	0.00
2.00	.50	0.00	.10	.40	25.22	.75
3.00	.50	0.00	.50	0.00	22.80	.60
4.00	.40	.10	.50	0.00	17.00	1.00
5.00	.25	.10	.65	0.00	15.50	1.20
12.00	.70	0.00	0.00	.30	22.50	.80
13.00	.80	0.00	0.00	.20	29.00	.40
14.00	.75	0.00	0.00	.25	24.00	.60
15.00	.47	.16	.33	.04	19.00	.92
16.00	.49	.09	.18	.24	21.30	.82
17.00	.50	.09	.18	.23	19.50	1.05
18.00	.43	.16	.37	.04	13.50	.89
19.00	.28	.16	.55	.01	11.50	1.15
20.00	.24	.14	.61	.05	11.50	1.70
21.00	.13	.09	.78	-0.00	14.00	3.00
22.00	.26	.15	.58	.01	14.80	1.81
23.00	.24	.42	.36	0.00	12.80	1.90
24.00	.20	.54	.28	0.00	4.50	1.00
25.00	.16	.63	.22	0.00	2.50	1.00
26.00	.21	.52	.29	0.00	7.40	.70
27.00	.23	.48	.31	0.00	7.00	.90
28.00	.31	.34	.37	0.00	9.00	.95
29.00	.37	.27	.37	0.00	11.00	.90
30.00	.35	.27	.38	0.00	11.00	.80
31.00	.51	.09	.17	.23	22.50	.70
32.00	.49	.09	.17	.25	21.00	.70
36.00	.14	0.00	.86	0.00	13.00	5.00

	Source			
	Trinity River	Houston Ship Channel	Other	Total
Water Discharge, 1000 CFS	5.58	10.54	2.79	18.90
Waste Discharge, million pounds of BOD/yr.	29.90	153.2	52.20	235.3

Analysis of rainfall data (U.S. Weather Bureau) indicates that 1969 and the preceding two years were "average".

From these water and waste discharge information and the seasonal detritus curves of Heald (1971) for a South Florida Bay a detritus input curve was determined for the Galveston Bay. Significant considerations were that 1) biological oxygen demand (BOD) reported by Armstrong and Hinson (1973) inherently included waste products as well as detritus (organic particulates); 2) due to similar ecosystems (having many of the same species) marsh and submerged grasses would tend to have similar seasonal cycles, even if displaced by several months; and 3) maximum and minimum value ratios of detritus densities would be approximately the same for the two ecosystems. The resultant detritus (organic particulates) input curve to the Galveston Bay for the calendar year 1969 is shown in figure 3. Detritus loads for subsequent years are discussed in Appendix A.

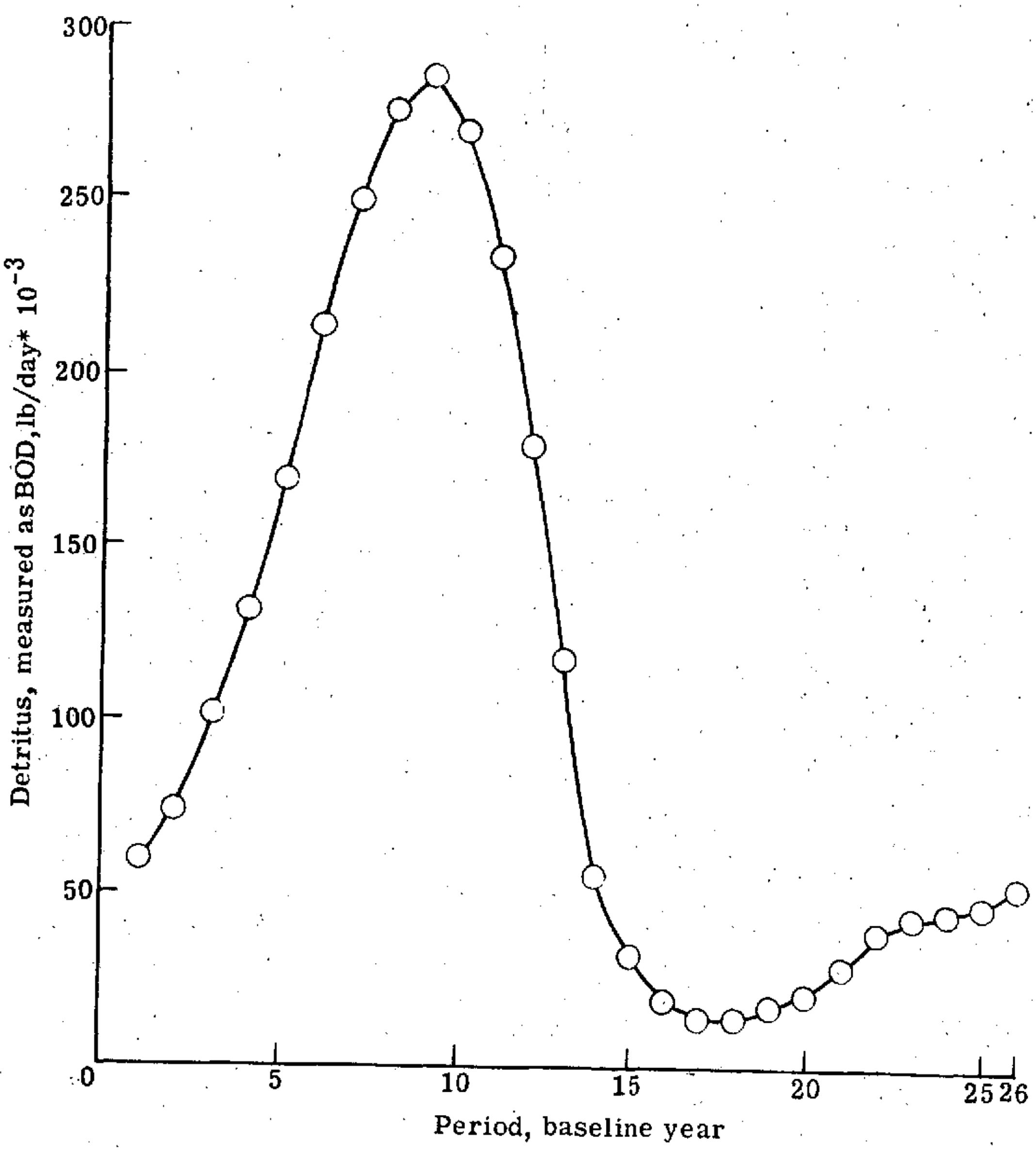

Figure 3.- Detritus input to Galveston Bay, 1969.

Results of biological sampling in the Galveston Bay in 1969 (Copeland and Fruh 1970) are summarized in figure 4. Paired curves are shown for the zooplankton counts and other consumer groups biomass (consumer groups will be defined in the following section). Biomass values are the sums from the individual stations, and will be reference levels in this study, rather than estimating total ecosystem biomass values.

The Galveston Bay Ecosystem

Temperate zone ecosystem characteristics are dominated by an annual seasonal cycle that is, in general, controlled by weather (Chin, 1961). Processes in the ecosystem are related to energy sources (food) and migrating consumers with physiological adaptations that allow them to effectively compete for the available foods.

In the Galveston Bay ecosystem freshwater flow from the feeding rivers brings in large quantities of organic particulates (detritus) and dissolved nutrients which serve as energy sources for the base of the feeding chain. Dissolved nutrients are necessary for growth of marsh grasses (*Spartina spp*), fixed bottom plants (turtle grass, *Thalassia testudinum*, for example) and small floating plants (phytoplankton). These materials are grazed or filtered from the water by small animals such as zooplankton, herbivores (shad, *Dorosoma cepedianum* and menhaden, *Brevoortia partronus*) and omnivores (shrimp, *Penaeus* spp and crabs, *Callinectes sapidus*). These small animals are in turn consumed by larger carnivore species (Atlantic croaker, *Micropogon undulatus*, Anchovy, *Anchoa mitchilli* and Trout, *Cynoscion arenarius*). A generalized energy flow diagram for the Galveston Bay is shown in figure 5.

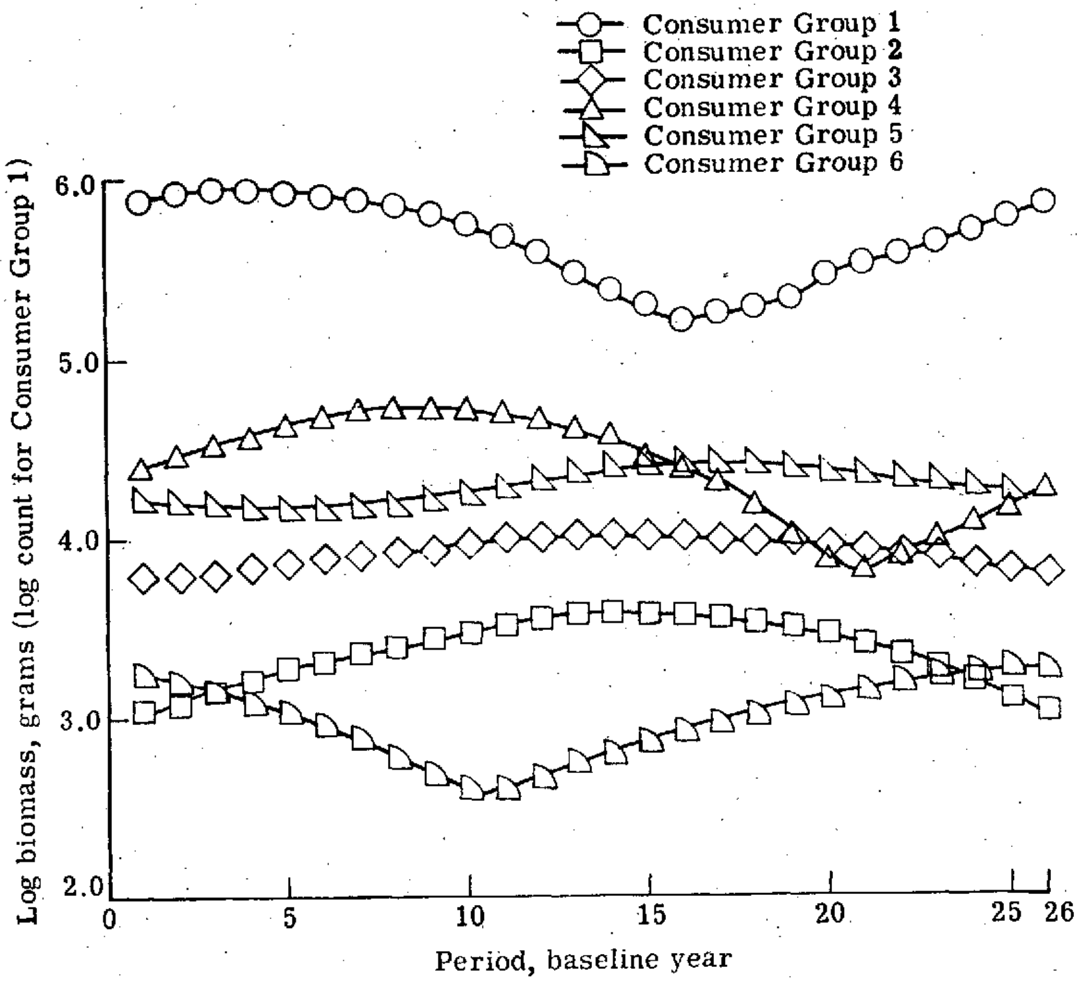

Figure 4.- Consumer group's biomass - Galveston Bay, 1969 (from Copeland and Fruh, 1970).

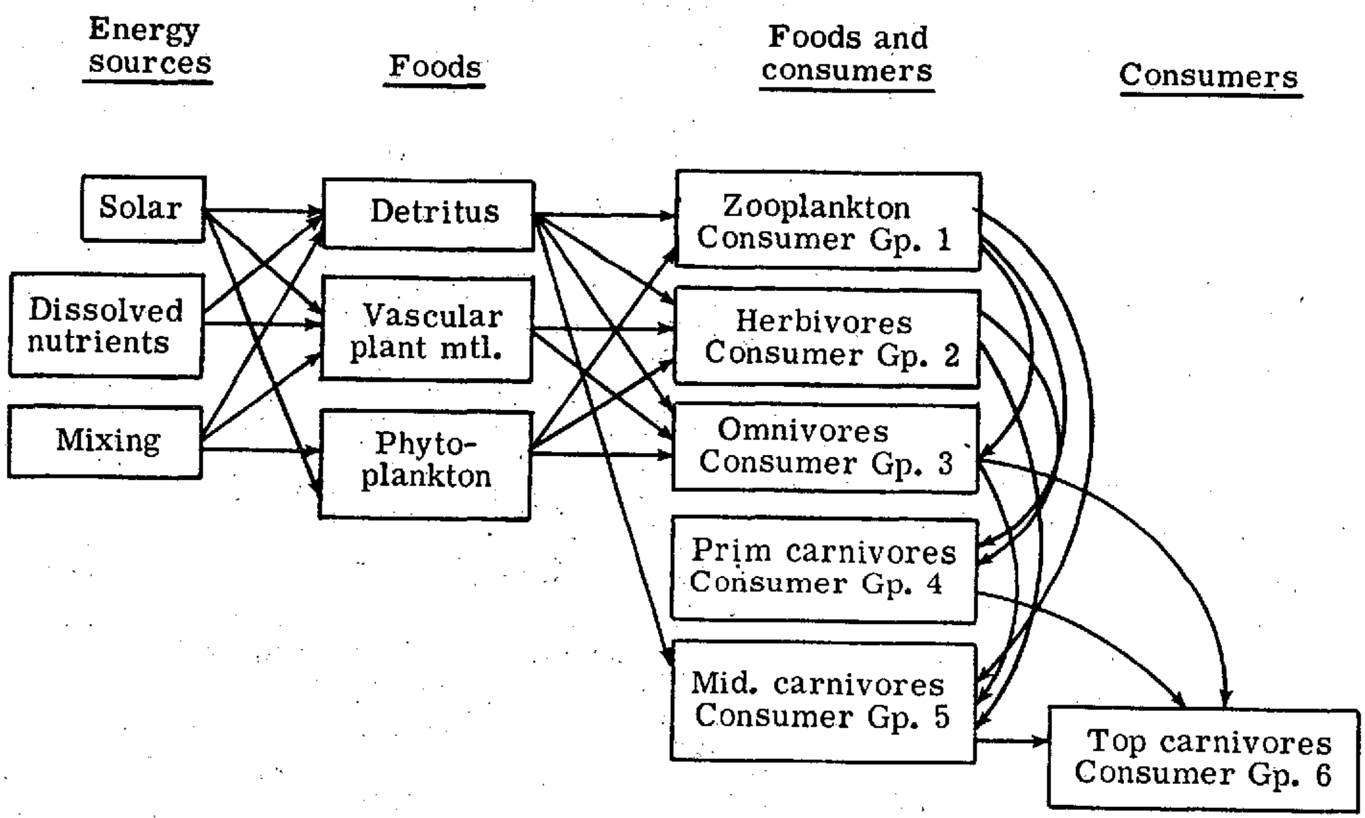

Figure 5.- Biological energy flow in Galveston Bay ecosystem.

One ecosystem characteristic is that certain functions are performed by one or more species, either simultaneously or over a period of time. For this reason, the biological species in the Galveston Bay may be grouped based on similarity of function and feeding characteristics. In this study consumer groups have been organized based on consuming habits and food preferences. Consumer groups and typical species in them are:

Consumer Group No.	Consumer Group	Typical Members
1	Zooplankton	
2	Herbivores	Menhaden
3	Omnivores	Shrimp
4	Primary Carnivores	Atlantic Croaker
5	Middle Carnivores	Anchovy
6	Top Carnivores	Trout

The above groupings are based on dominant characteristics in the first year or period of maximum rate of growth in the ecosystem. Adults may not consume the same foods as the young of the same species; however, this is not a limitation since consumer groups and shifting of consuming habits are included in the model.

Feeding habits of estuarine species have been studied extensively by Darnell (1958, 1961) and W. E. Odum (1971). Based on their results foods curves have been developed for the six consumer groups, figures 6-11.

Productivity (i.e., growth of biomass in the estuary followed by harvesting or catches) either in the estuary or after it has left the estuary, is one of the uses of an estuarine system. It provides food,

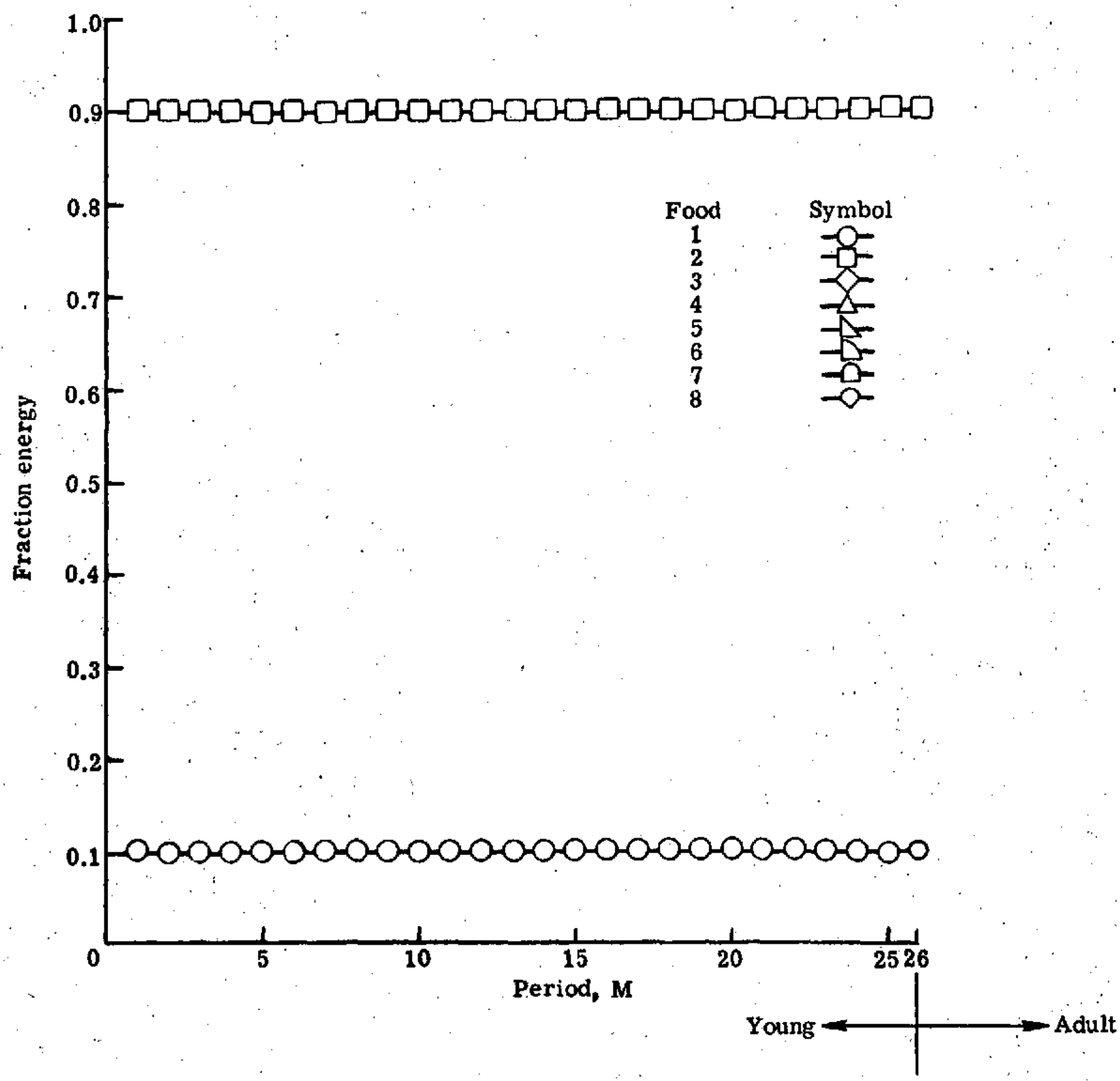

Figure 6.- Energy sources for consumer group 1.

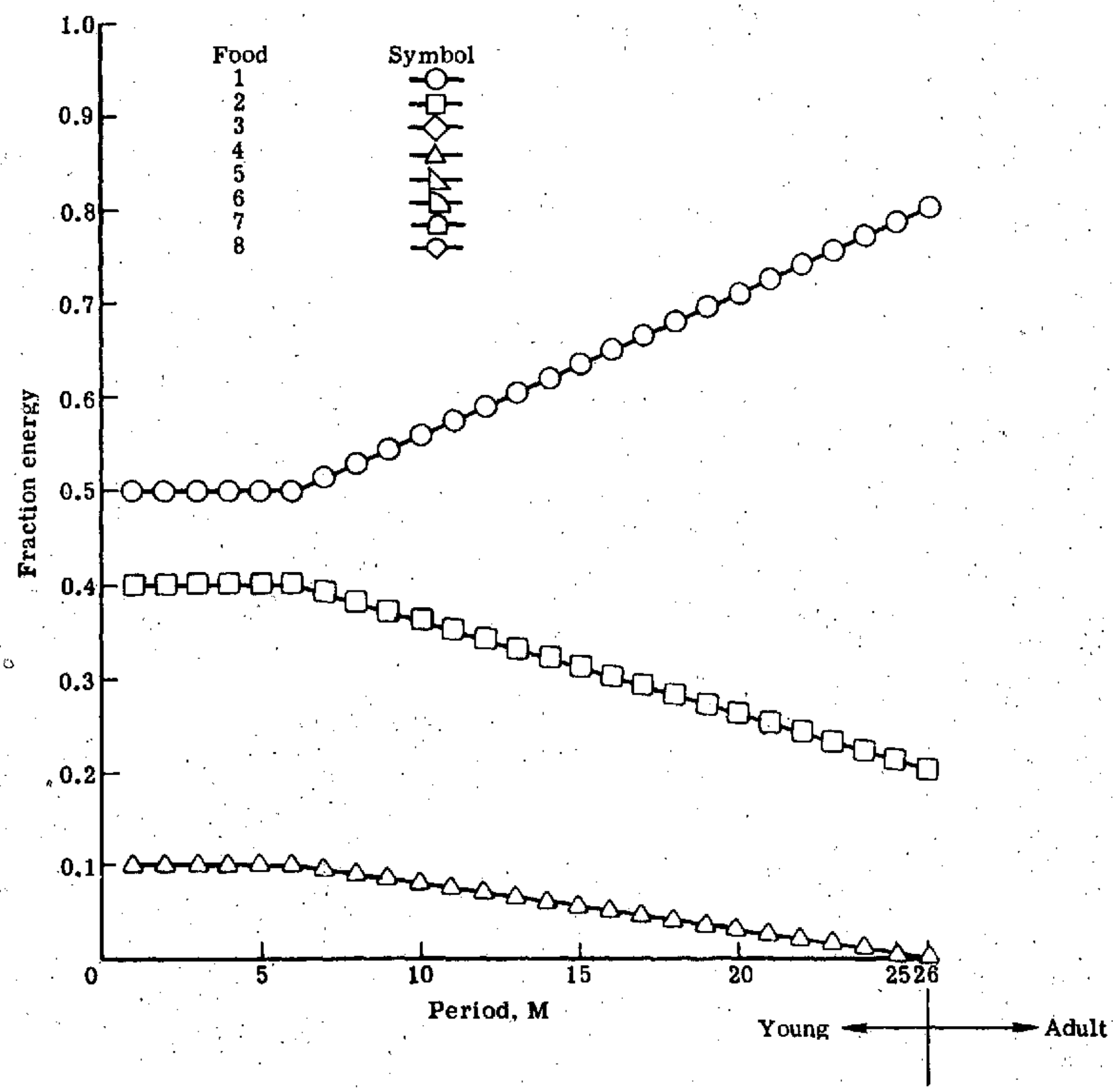

Figure 7.- Energy sources for consumer group 2.

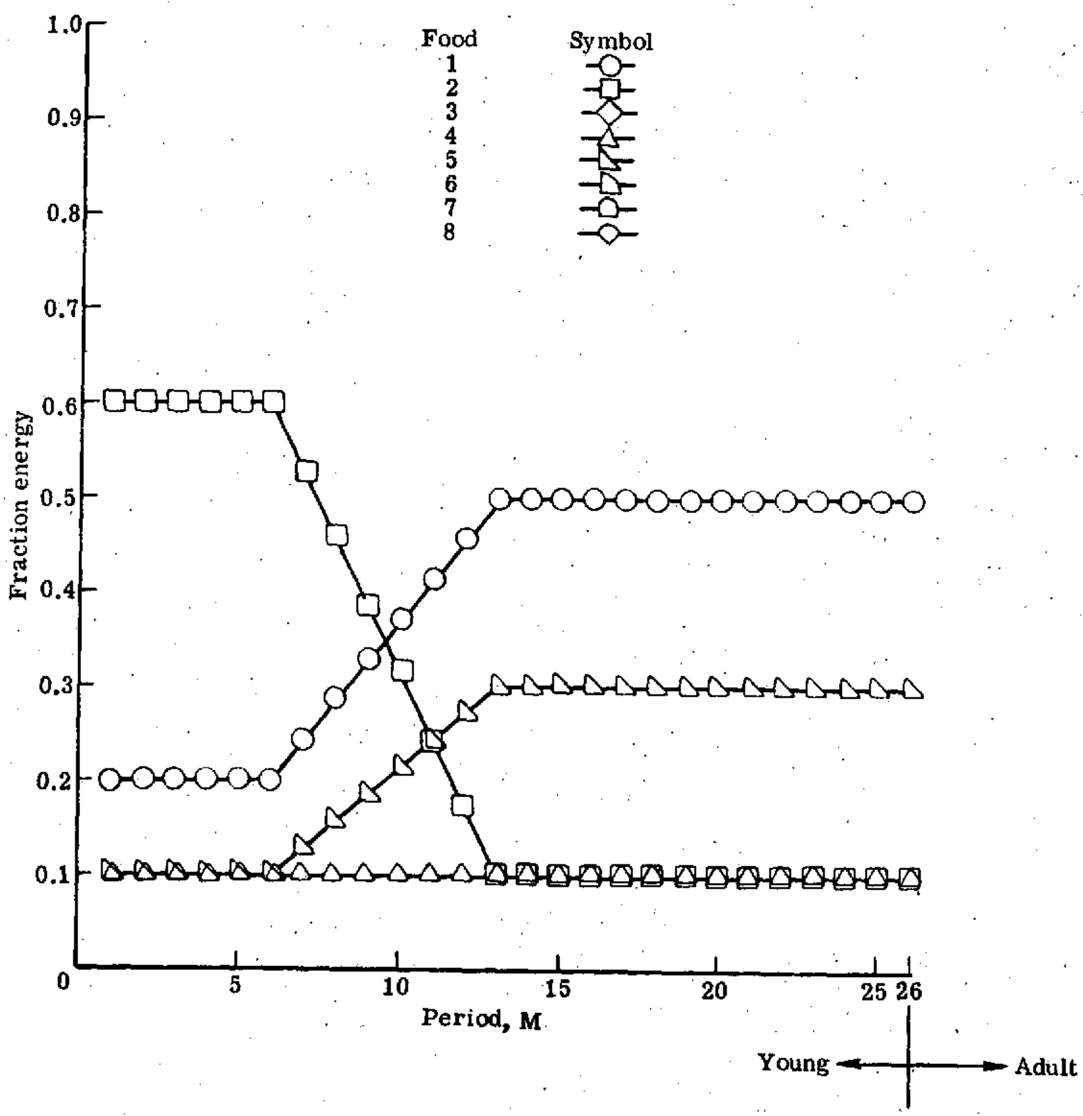

Figure 8.- Energy sources for consumer group 3.

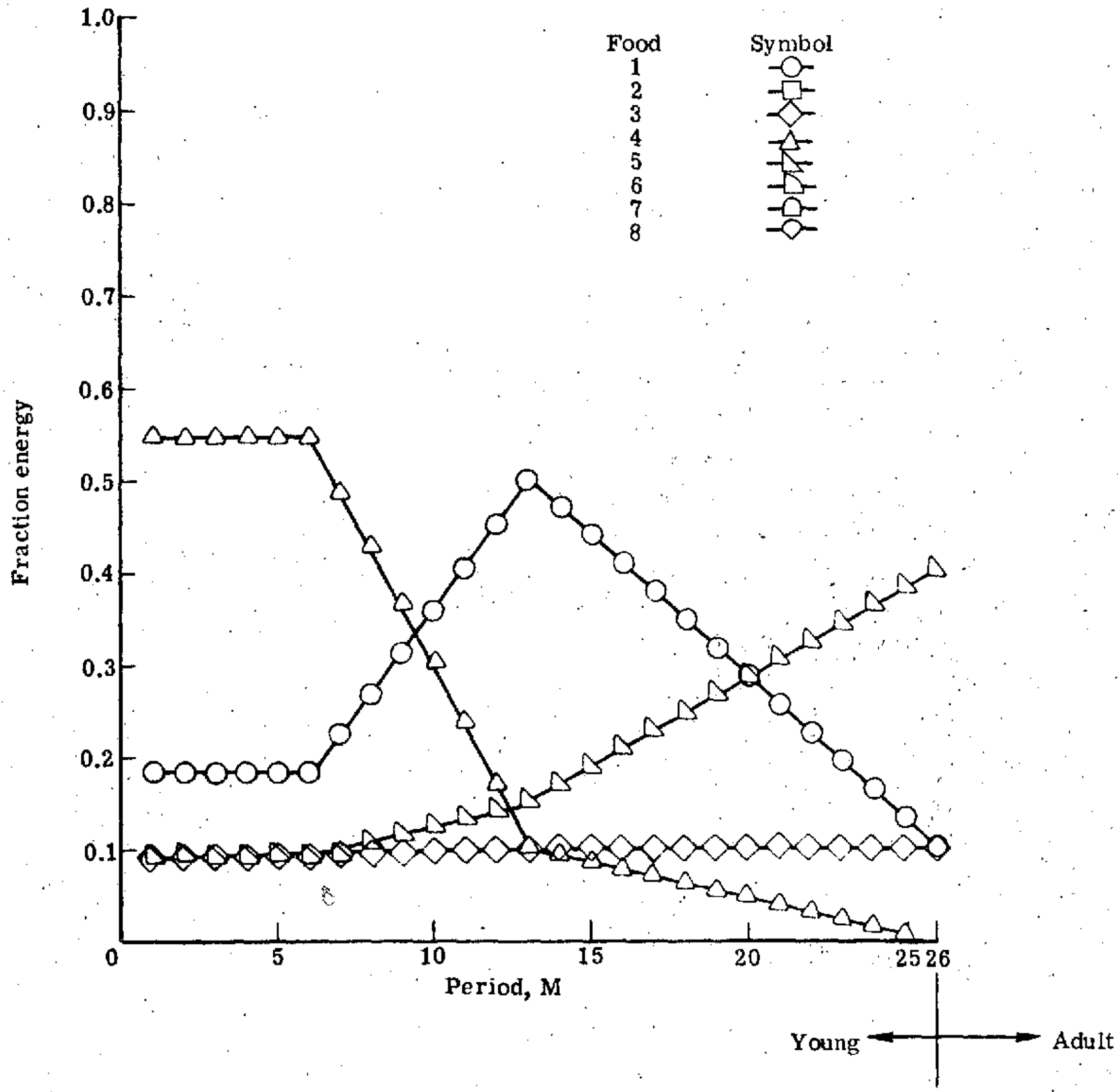

Figure 9.- Energy sources for consumer group 4.

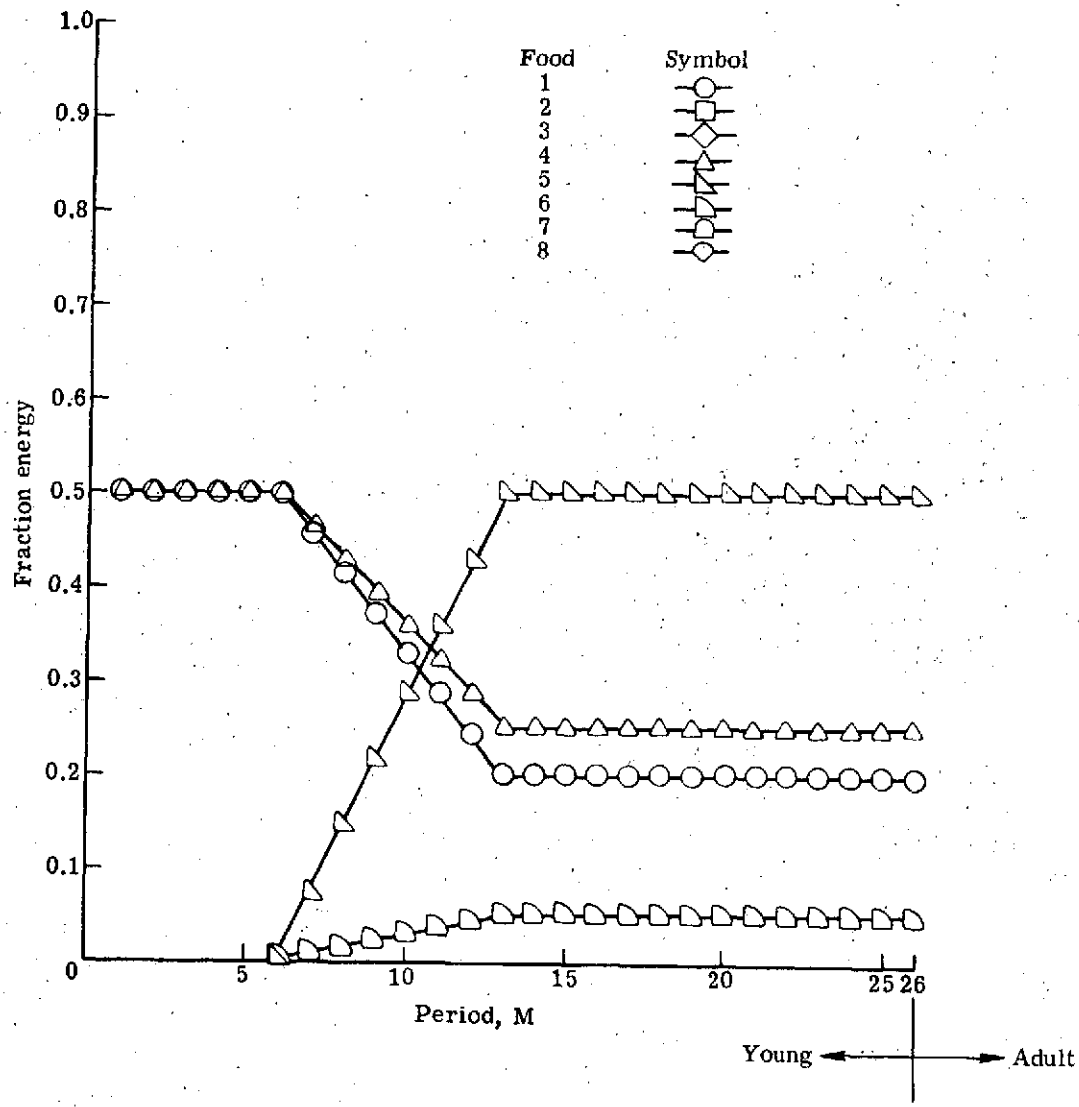

Figure 10.- Energy sources for consumer group 5.

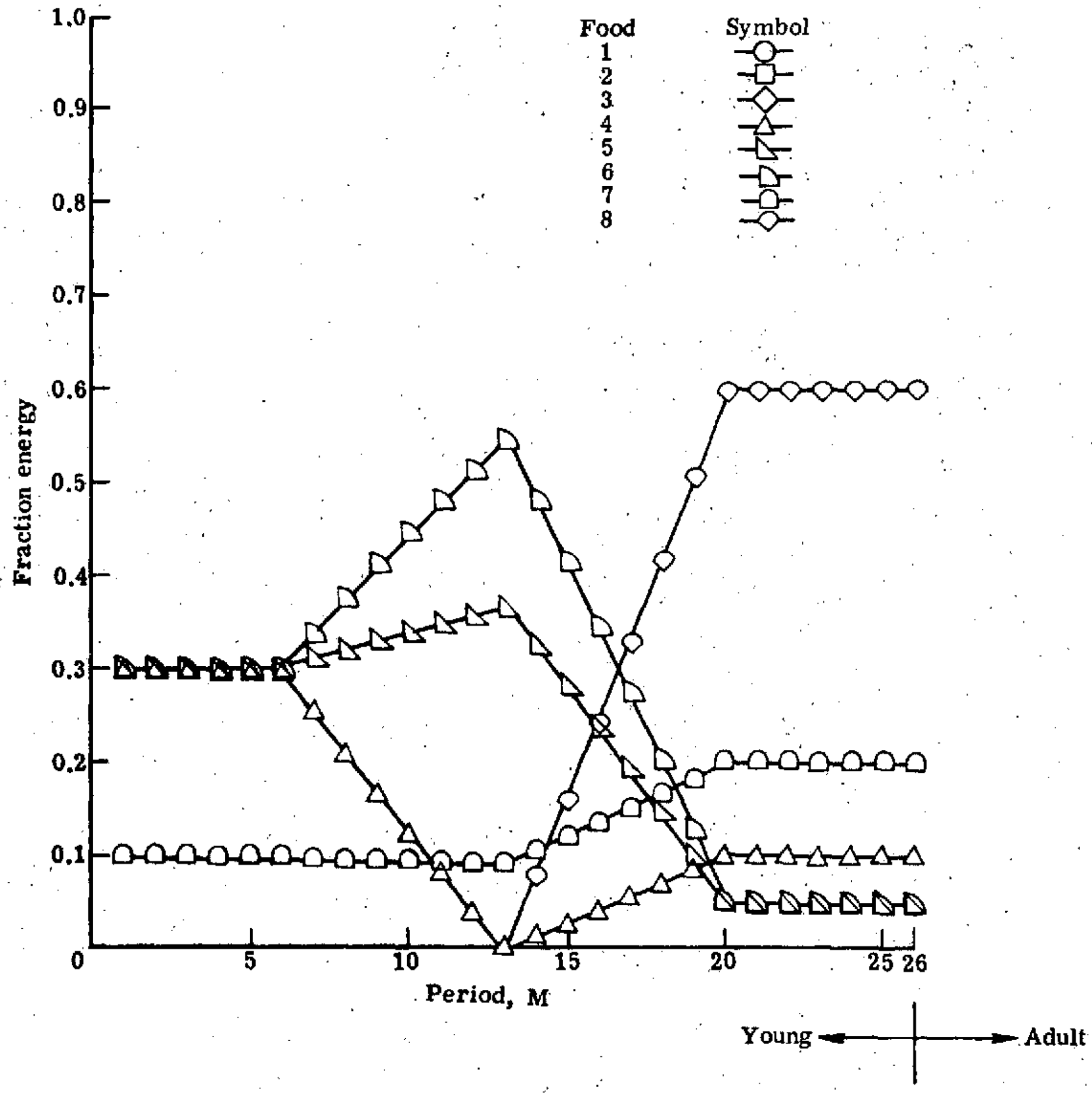

Figure 11.- Energy sources for consumer group 6.

employment and other economic benefits and is one measure of the value of an estuary.

Productivity in the estuarine system as indicated previously is determined by immigration, growth, and emigration. Thus, the estuary meets a specific need for the species of interest during some period of their lifetime. Immigration and emigration are largely natural phenomena that represent an adaptation of particular species to the total environment in which they live and are not directly controllable or manageable by man. (Perhaps this is also due to the fact that the total system, which includes the oceans, is too big!) On the other hand, the growth phase of estuarine organisms is highly affected by man's activities, particularly pollution due to waste discharges and manipulation of water flows into or within the estuarine system (Odum, Copeland, and McMahon 1969).

Factors identified as primary in the growth of estuarine species are:

1) Food and consumer densities;
2) Environmental effects, including pollution; and
3) Distribution effects, which are related to geological parameters.

Other parameters, such as temperature, are obviously important, (*e.g.*, Gunter, 1957) but do not appear to be controlling factors in changes in the Galveston Bay at this time. In any event, it appears that their relation to growth *per se* are secondary compared to the three factors listed above.

Food and consumer densities and their effect on consumer growth rates have been studied by Brocksen, Davis and Warren (1970). In the

relatively confined basins and lakes in which their studies were conducted on sockeye salmon (Oncorhynchus nerka) there was a linear relation between consumer biomass and growth rate, figure 12. Extrapolation to a zero growth rate at some consumer density is questionable, and, as they pointed out, even in the lowest food producing areas, they did not measure a zero growth rate. Consumer growth rate as a function of food density was also a part of the above study. In this case food preference of the salmon was very specific to zooplankton and salmon growth rates had a direct correlation to zooplankton densities over a wide range, figure 13.

Effects of pollution, whether nutrients or toxic materials, has been well established and has significant effects not only on specific species but on communities as well (Copeland, 1966; Steed and Copeland, 1967; and Wohlschlag and Cameron, 1972). However, quantitative relationships over the period of an organisms or species life cycle has not been established. Alderdice and Brett (1957) and Brett (1957) investigated the effects of kraft paper-mill wastes and hydroelectric power plants on the growth and survival potential for salmon during their migrations. One of their significant concepts was that relatively small increases in stress (due to pollution or environmental factors) could lead to significant loss of competitiveness and possible elimination. Steed and Copeland (1967) reached similar conclusions from studies on pinfish (Lagodon rhomboides) using petroleum waste effluents. Wohlschlag (1972) studied the effects on metabolism of the relatively polluted Galveston Bay waters compared to those in Aransas Bay (collected on incoming tide thus essentially

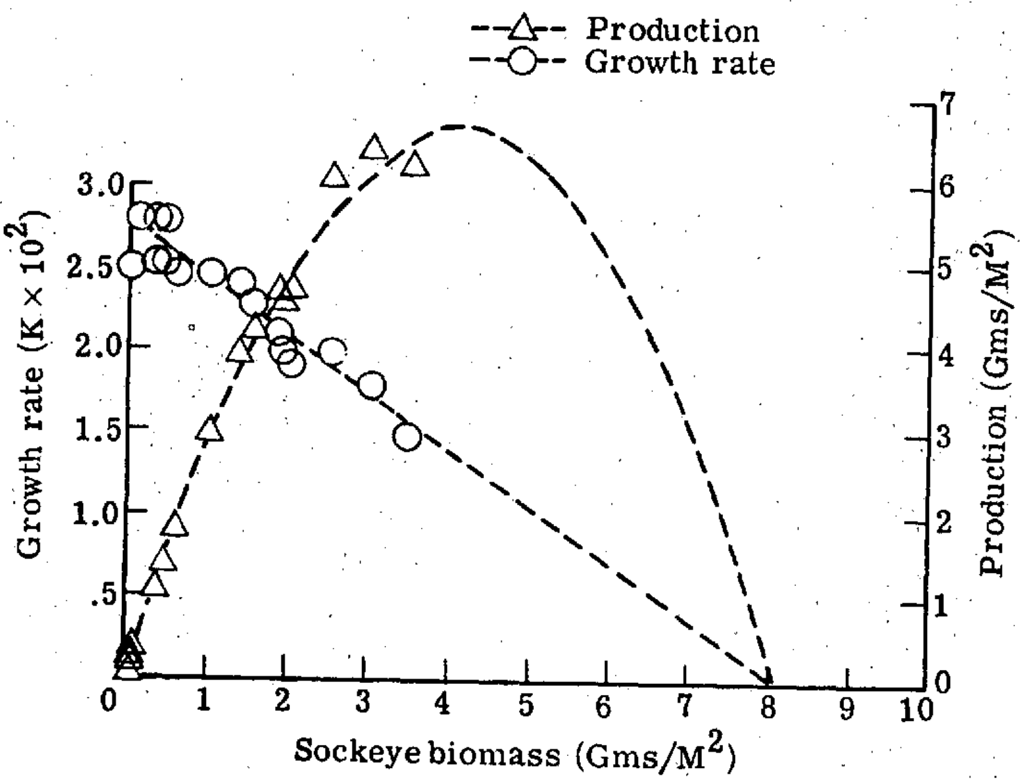

Figure 12.- Consumer growth rate as a function of consumer biomass (taken from figure 2, Brockson, Davis and Warren, 1970).

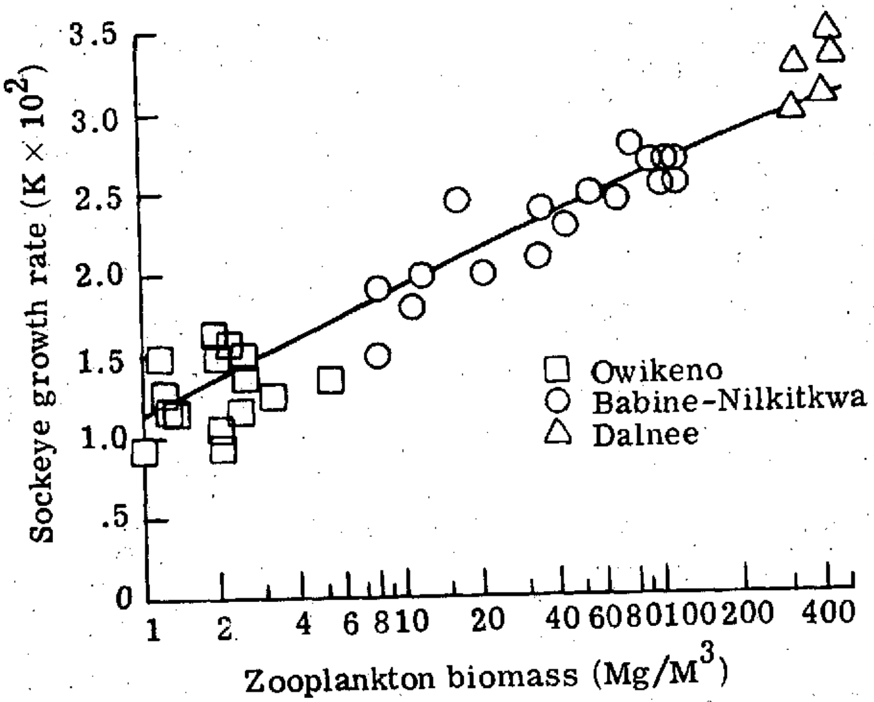

Figure 13.- Consumer growth rate as a function of food availability (taken from Brocksen, Davis and Warren, 1970).

pollution free) using striped mullet (Mugil cephalus). His results indicated about a 10% reduction in metabolism and probably at least that much reduction in growth.

Freshwater inflow into Texas Coastal Bays is a significant factor in their productivity. In addition, as observed by Hildebrand and Gunter (1953), Copeland (1966), and Armstrong and Hinson (1973), the effects are species specific and, on commercial catches (such as shrimp), may have a one to two year lag. Copeland (1966) studied the effects of freshwater inflow as a function of bay or estuarine size and location; Armstrong and Hinson (1973) subsequently refered to this as displacement rate. In general in a specific estuary, such as the Galveston Bay, total commercial catch increased with decreased freshwater input (at least to the point of a significant ecosystem shift); however, the decreased freshwater flow led to higher production of finfish species such as the Atlantic Croaker at the expense of the more economically desirable shrimp and crabs. Armstrong indicated this may be due to decreased spawning and feeding areas as a result of higher salinities in the bordering marsh areas. Data from the above studies are discussed in section III on model calibration.

It is interesting that, largely due to the magnitude of the problem, it has been only recently that studies of multiple effects and their interactions have been initiated and analyzed (e.g., Alderdice 1963, 1972). However, we would intuitively recognize that an environmental effect is not constant but varies as a result of other parameters.

This condition has been well established for salinity-pollution (Copeland and Fruh, 1970) and for temperature-growth (Kinne 1965, 1967); however the effect has not been quantitatively established in a natural growth situation, as is being evaluated in this study. Identified growth effects used in this study have been reported from prior studies of them as independent factors. Interactions may be included in some of the effects reported; however, they are probably of secondary importance, as for temperature.

SIMULATION MODEL OF THE GALVESTON BAY

A continuous simulation model format (Forrester 1961) is used for the Galveston Bay ecosystem. Independent variables are exogenous changes in freshwater and waste discharge to the ecosystem. Dependent variables, or outputs, are biomass levels of six identified consumer groups. Analytical and empirical relations are used to define and relate physical, chemical, and biological characteristics of the ecosystem.

This section provides a functional description of the model. A detailed description, including equations, is in Appendix A and a program print-out in Appendix B. For clarification, it may be useful to review the previous section describing the ecosystem.

The model

In an estuarine ecosystem, as discussed previously, the dominant cycle is the seasonal calendar year. In the model, the calendar year is divided into 26 two week periods (designated as $I = 1,\ldots,26$). These periods were short enough that rate changes within the period are insignificant.

Each of the six consumer groups (designated as $L = 1,\ldots,6$) is phased into the yearly cycle, but their own cycle is different from the others, as shown in consumer biomass curves developed from sampled and historical data for the initial model (baseline) year, figure 4. Each consumer group's seasonal cycle (periods designated by M) starts with $M = 1$ defined as the period when a consumer group's biomass is at a minimum

in the ecosystem (e.g., M = 1 in period I = 21 for consumer group 4). The biomass in the estuary at M = 1 is assumed to be residual, and is therefore designated as "adult" (as contrasted to this year's young or the immigration into the ecosystem). The seasonal cycle and its relationship to the calendar year is shown schematically in curve "e" of figure 14.

Immigration starts in period M = 1 and continues over 3-4 model periods (6-8 weeks). Functionally, it is taken to be a sinusoidal shaped curve (positive 180°) and is shown schematically as curve "a" of figure 14. Immigration is a constant from year to year, independent of ecosystem variations (Caillouet and Baxter 1973; Copeland 1973).

Immigrated (larval and post-larval) organisms have very high growth rates decreasing with increasing organism size (Paloheimo and Dickie 1965; Patten 1971). A decreasing value exponential function is used for the base-line year to describe the growth rate over a consumer group's year, decreasing to a value of 0 for adults (e.g., beginning of the next year). Base-line year growth rates are shown schematically as curves "b" and "c" for immigrated and adult organisms, respectively. Note that in the base-line year all growth rate effects due to changes in exogenous variables have, by definition, values of 0 (or a multiplier of 1.0). In subsequent years, year to year changes in the exogenous variables are defined in terms of growth rate change ratios, which are used to determine new values for net growth rates.

After high growth rates in the estuary, consumer organisms emigrate from the ecosystem - in this case, primarily to the Gulf of Mexico. Emigration is shown schematically as curve "d" in figure 14.

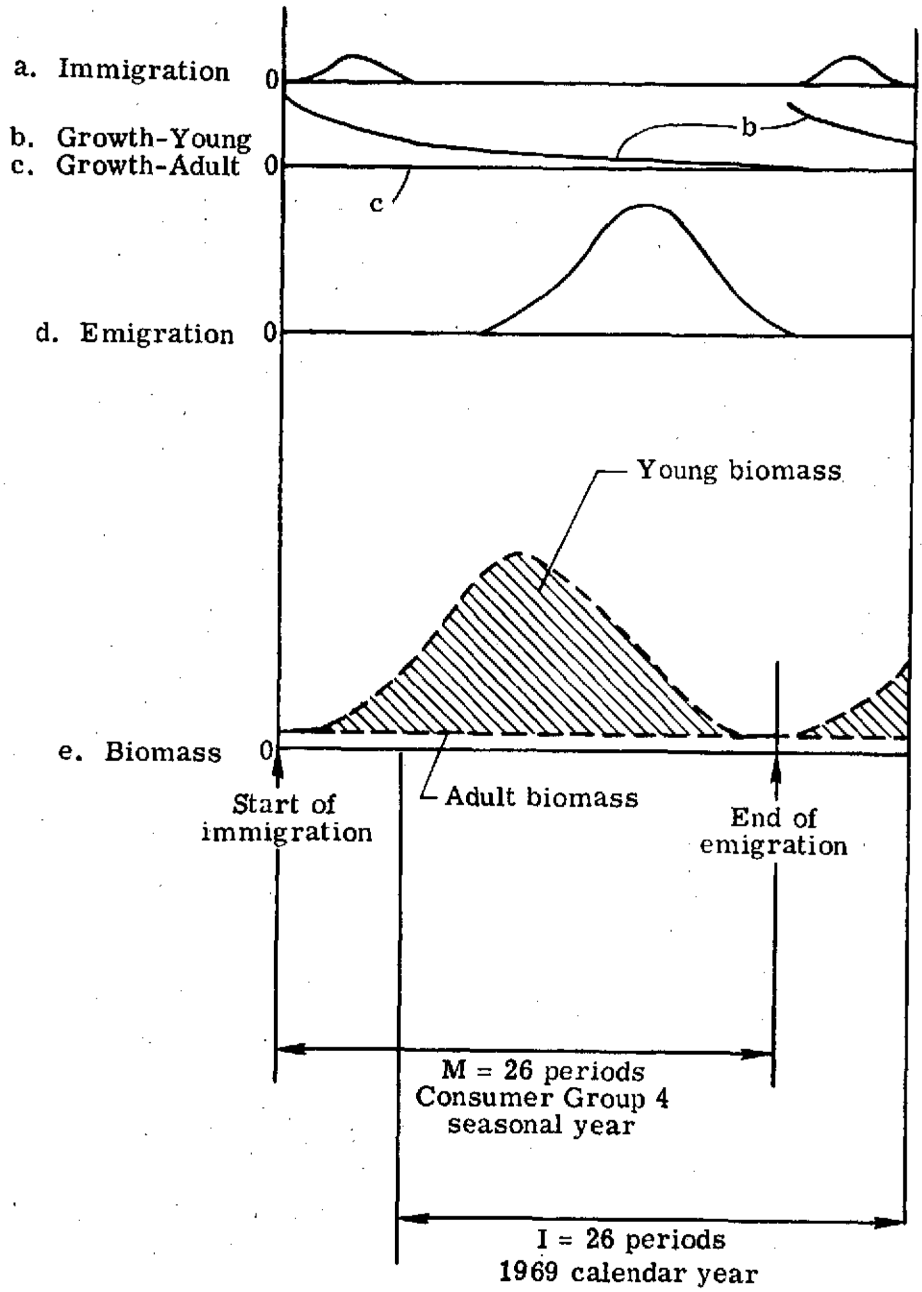

Figure 14.- Development of baseline year biomass curve for consumer group 4.

Consumer group 4 biomass for the base-line year is shown schematically as curve "e" in figure 14. Biomass curves (counts for zooplankton) for the other five consumer groups are independently developed in an analogous manner. These six curves are correlated with the calendar year periods (I), which are used for period identification after the base line year.

In the model, iterative calculations are made period by period. A period calculation consists of 1) determining the net period growth rate, which is the product of the prior year net growth rate and current year change ratios due to consumer and food densities and exogenous variables (in the baseline year the net growth rate is taken from the exponential curve); 2) to the biomass at the beginning of the period adding immigration and subtracting emigration; and 3) the total is multiplied by the net growth rate to obtain period biomass which is also the biomass at the beginning of the next period.

Model stability is aided by built-in safeguards which act as negative feedback; first, if environmental conditions remain the same, biomass curves will repeat the previous year's values, except for time-lag effects; second, in the food and consumer density function the growth rate ratio is an inverse function of consumer density compared to the baseline year value (in effect this implies an upper limit on consumer biomass in the ecosystem) (equation 8, Appendix A); and third, model calibrations and examples are based on wide ranges of freshwater and pollution inputs that occurred over about a 20 year period (sections II, 1,b and IV).

The Baseline Year

In 1969 a comprehensive sampling program was accomplished as part of the Galveston Bay Program (Copeland and Fruh, 1970). Results of this sampling program have been used to determine numerical parameters for seasonal changes in consumer group biomass levels for the Galveston Bay pollution effects model (i.e., biomass curves expressed in model language). For this base-line year, all growth change ratios are set equal to 1.0. This allows the development of growth rates for the conditions that existed during the base-line year.

As developed in the previous section, biomass curves for each of the consumer groups includes immigration, growth in the ecosystem, and emigration. Typical of lower temperate region ecosystems, year-round populations remain in the estuary. In the model the biomass in the ecosystem at the minimum biomass of a consumer group is taken as "adult" or the year-round population. As noted previously in the model section, this period of minimum biomass is the start of that consumer group's seasonal year (M = 1 for that consumer group). Pertinent events in the development of the base-line year biomass curve and numerical values for consumer group 4 are (see figure 14):

	Period	
Event*	I	M**
Start of Immigration	21	1
End of Immigration	25	5
Start of Emigration	4	10
End of Emigration	21	1

*See Appendix A for model detail.
**M relates to baseline year only

Numerical Values*

Constant of Immigration	1600
Factor of Emigration	.20
Growth Rate Factor	1.20

*See Appendix A for model detail.

The model biomass curve is shown in figure 15. Values from the sampling program (Copeland and Fruh 1970), are also shown.

Model Calibration

Model calibration, or development of numerical equations to describe changes in growth rates as a result of changes in food and consumer densities and exogenous variables, is based on a number of independent investigations, each of limited scope. In the model, as in the studies, factors other than those being evaluated will be held constant during that phase of model calibration. Effects on consumer group growth rates will be evaluated in the following order:

1) Food and consumer densities;
2) Environmental effects; and
3) Distribution effects.

Growth rate effects due to consumer and food densities were studied by Brocksen, Warren and Davis (1970) as discussed previously, figures 12 and 13. Specific model equations are developed in the Appendix.

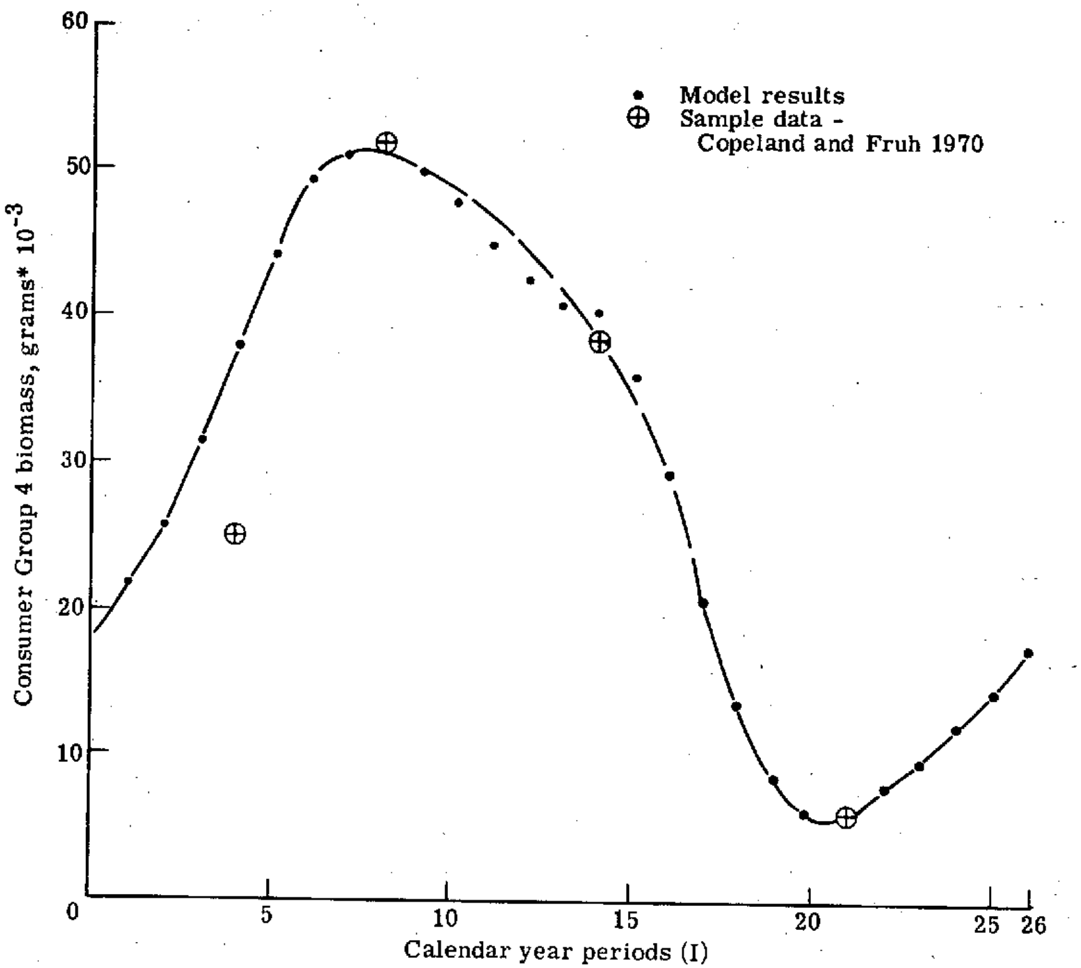

Figure 15.- Resulting year model biomass curve and sample data for consumer group 4.

Environmental effects on growth - primarily due to pollution effects - have been investigated by Wohlschlag (1972) as discussed previously. Growth effects are assumed to vary linearly with the pollution parameter.

Distribution effects in the Galveston Bay are due primarily to changes in freshwater inflow. Investigations by Copeland (1966) and Armstrong and Hinson (1973) have evaluated shrimp and total biomass productivity as influenced by freshwater inflow and/or Galveston Bay water displacement rate, both of which are directly relatable to salinity and pollution concentrations. Figure 16 shows a replotted data curve from Copeland (1966) and shrimp productivity by the model for programmed variations in freshwater discharge. There is a two year displacement (lag) of shrimp productivity change to freshwater input as discussed previously.

Total productivity in the Galveston Bay ecosystem is also a function of freshwater inflow. Figure 17 shows the replotted data of Armstrong and Hinson (1973) compared to model results for a range of freshwater inflows.

Galveston Bay ecosystem consumer group productivity ratios (of the current year to the base-line year) for increased freshwater inflow conditions are shown on figure 18. Standing crop biomass levels for the six consumer groups are shown in figures 19 through 24. Table II lists the physical and chemical parameters and ecosystem productivity as measured by consumer emigrations.

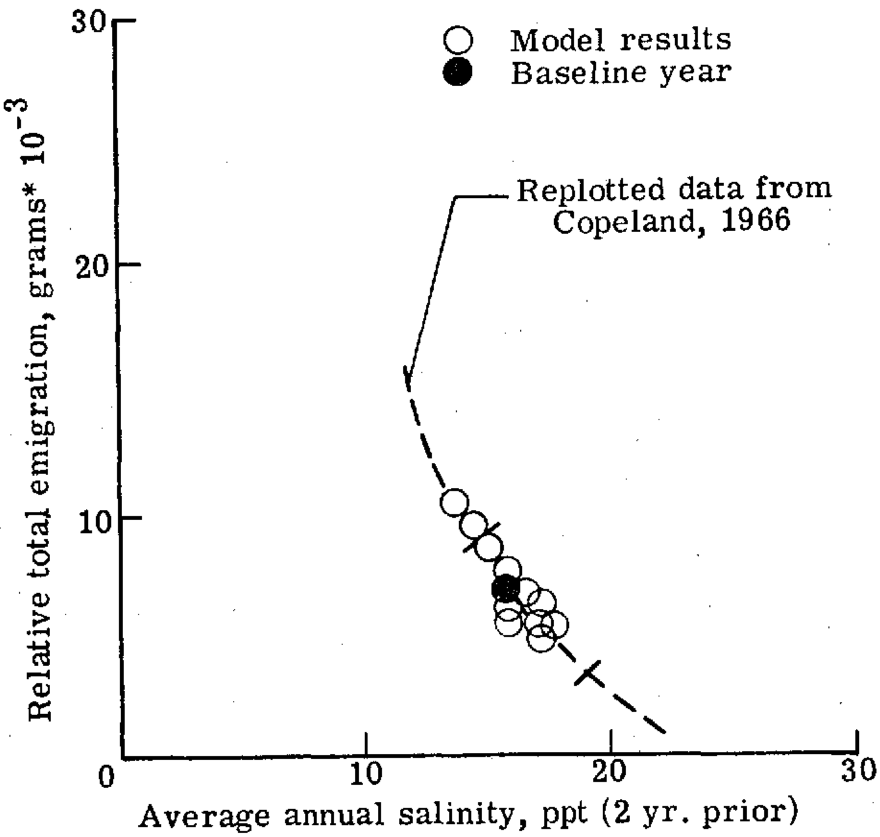

Figure 16.- Calibration curve for consumer group 3 due to variation in salinity (resulting from changes in freshwater inflow).

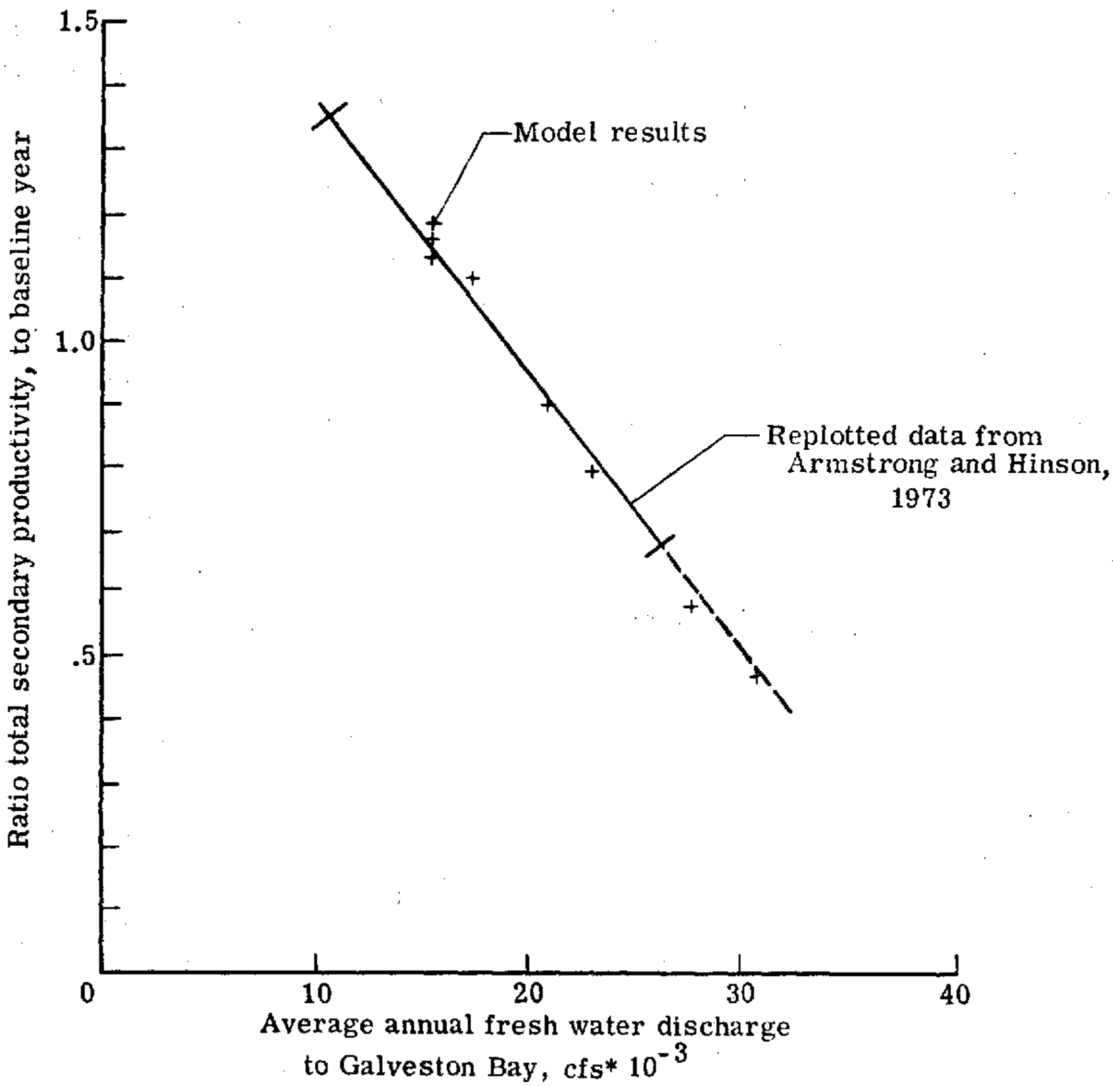

Figure 17.- Model calibration of total secondary production to freshwater discharge to Galveston Bay.

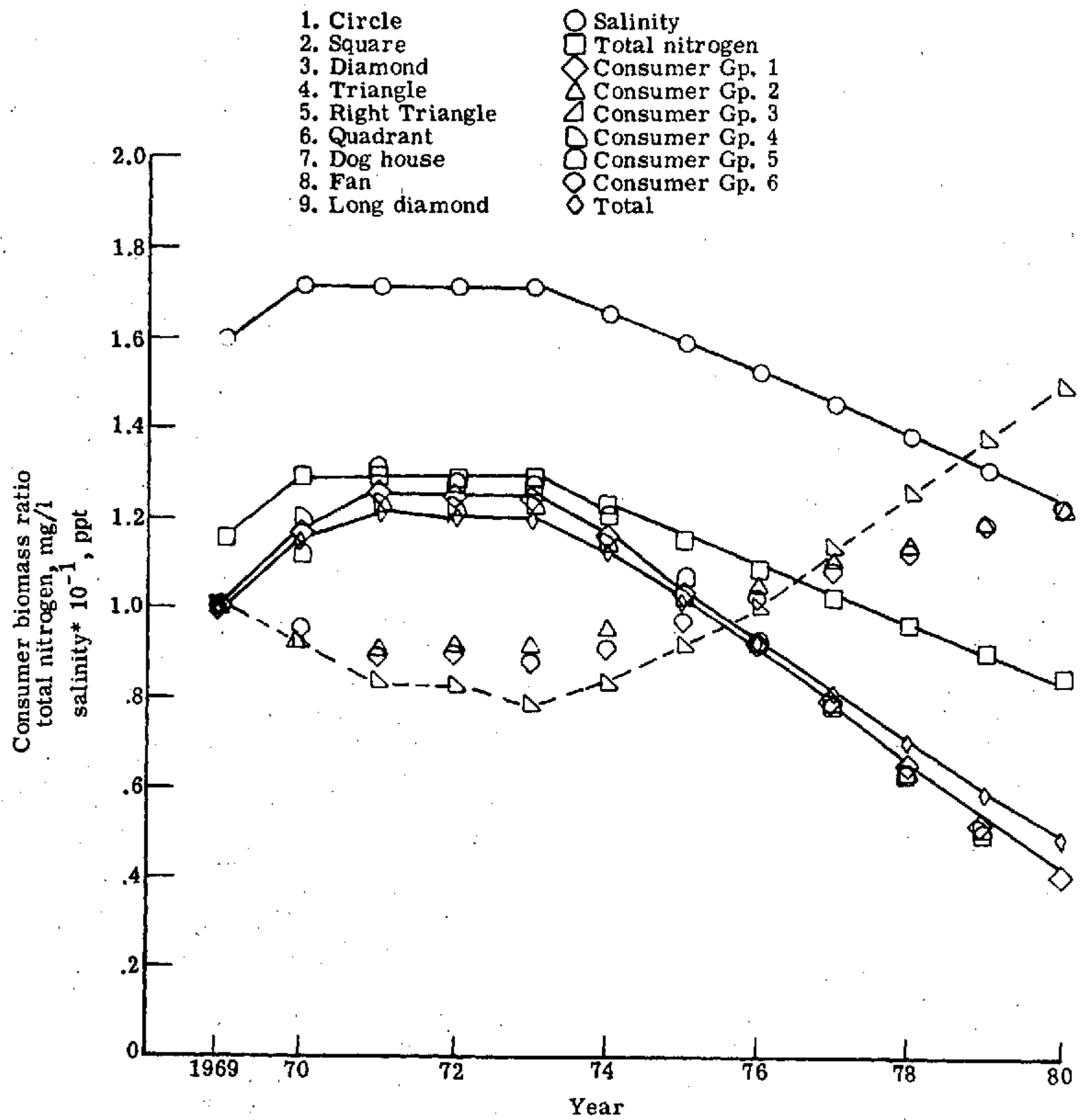

Figure 18.- Galveston Bay productivity ratios for consumer groups and total biomass due to increased freshwater inflow.

Table II: Consumer group and total productivity in Galveston Bay as a result of increased fresh water inflow.

Year		Freshwater Inflow cfs* 10^{-3}	Waste BOD, lb/yr $*10^{-6}$	Salinity, ppt.	Total Nitrogen, mg/l
(1969)	1	1.89E+01	2.47E+02	1.59E+01	1.16E+00
	2	1.56E+01	2.47E+02	1.71E+01	1.29E+00
	3	1.56E+01	2.47E+02	1.71E+01	1.29E+00
	4	1.56E+01	2.47E+02	1.71E+01	1.29E+00
	5	1.56E+01	2.47E+02	1.71E+01	1.29E+00
	6	1.72E+01	2.47E+02	1.65E+01	1.22E+00
	7	1.89E+01	2.47E+02	1.59E+01	1.16E+00
	8	2.08E+01	2.47E+02	1.52E+01	1.09E+00
	9	2.29E+01	2.47E+02	1.46E+01	1.03E+00
	10	2.52E+01	2.47E+02	1.38E+01	9.63E-01
	11	2.77E+01	2.47E+02	1.31E+01	9.03E-01
	12	3.04E+01	2.47E+02	1.23E+01	8.46E-01

Year		Relative Consumer Group Emigration, grams						
		1*	2	3	4	5	6	Total
(1969)	1	9.33E+05	5.02E+03	6.87E+03	9.87E+04	3.08E+04	2.42E+03	1.44E+05
	2	1.09E+06	4.61E+03	6.33E+03	1.18E+05	3.45E+04	2.31E+03	1.66E+05
	3	1.17E+06	4.53E+03	5.68E+03	1.21E+05	4.03E+04	2.14E+03	1.74E+05
	4	1.16E+06	4.57E+03	5.64E+03	1.21E+05	3.95E+04	2.15E+03	1.73E+05
	5	1.16E+06	4.57E+03	5.35E+03	1.21E+05	3.89E+04	2.13E+03	1.72E+05
	6	1.09E+06	4.78E+03	5.66E+03	1.12E+05	3.70E+04	2.19E+03	1.62E+05
	7	9.70E+05	5.05E+03	6.28E+03	1.01E+05	3.27E+04	2.34E+03	1.48E+05
	8	8.52E+05	5.28E+03	6.93E+03	8.92E+04	2.83E+04	2.48E+03	1.32E+05
	9	7.29E+05	5.50E+03	7.79E+03	7.65E+04	2.40E+04	2.62E+03	1.16E+05
	10	6.07E+05	5.72E+03	8.61E+03	6.35E+04	1.95E+04	2.74E+03	1.00E+05
	11	4.91E+05	5.92E+03	9.42E+03	5.07E+04	1.53E+04	2.86E+03	8.42E+04
	12	3.84E+05	6.11E+03	1.02E+04	3.87E+04	1.14E+04	2.96E+03	6.95E+04

*Number

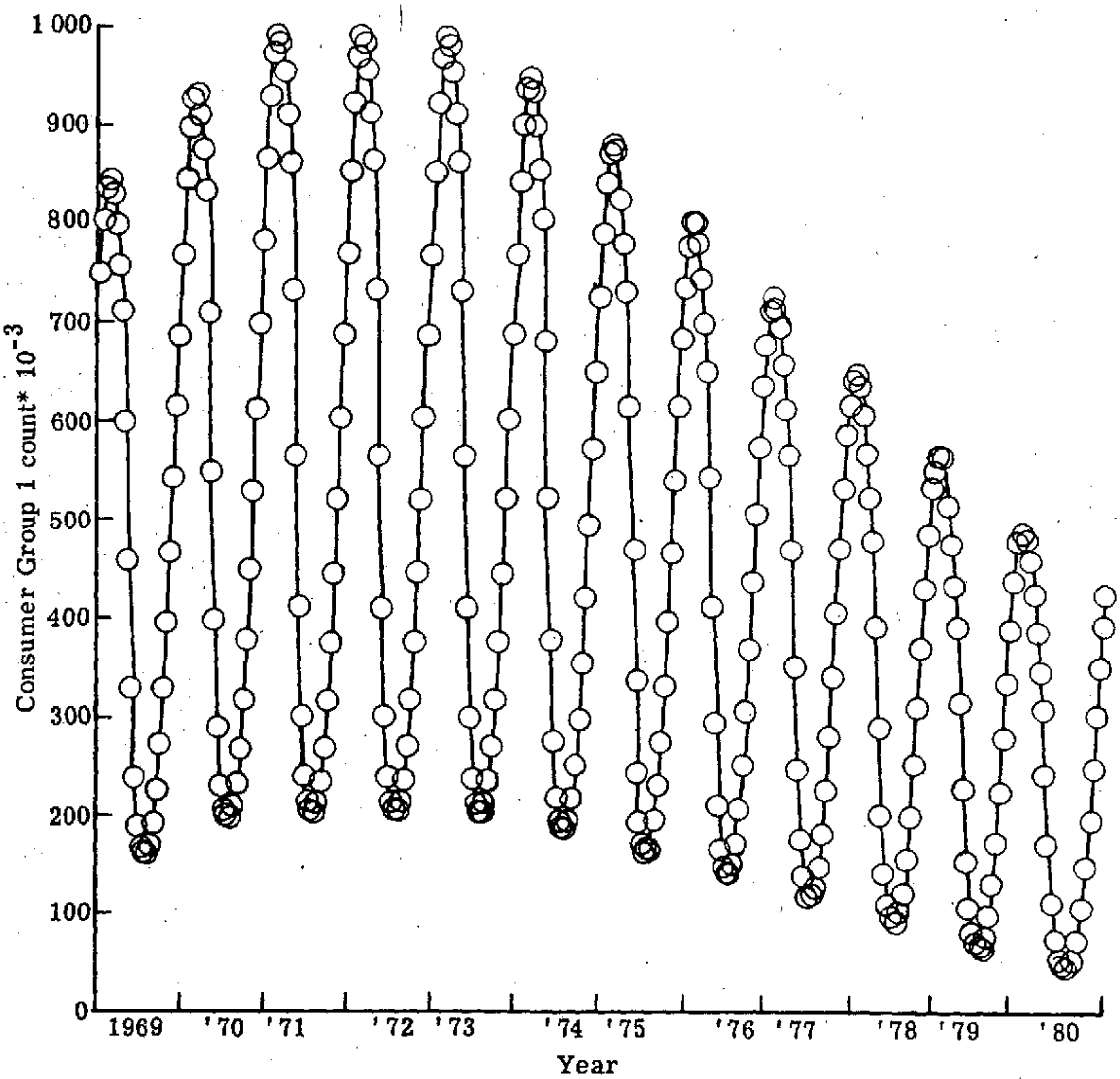

Figure 19.- Zooplankton standing crops during period of increased freshwater inflow to Galveston Bay.

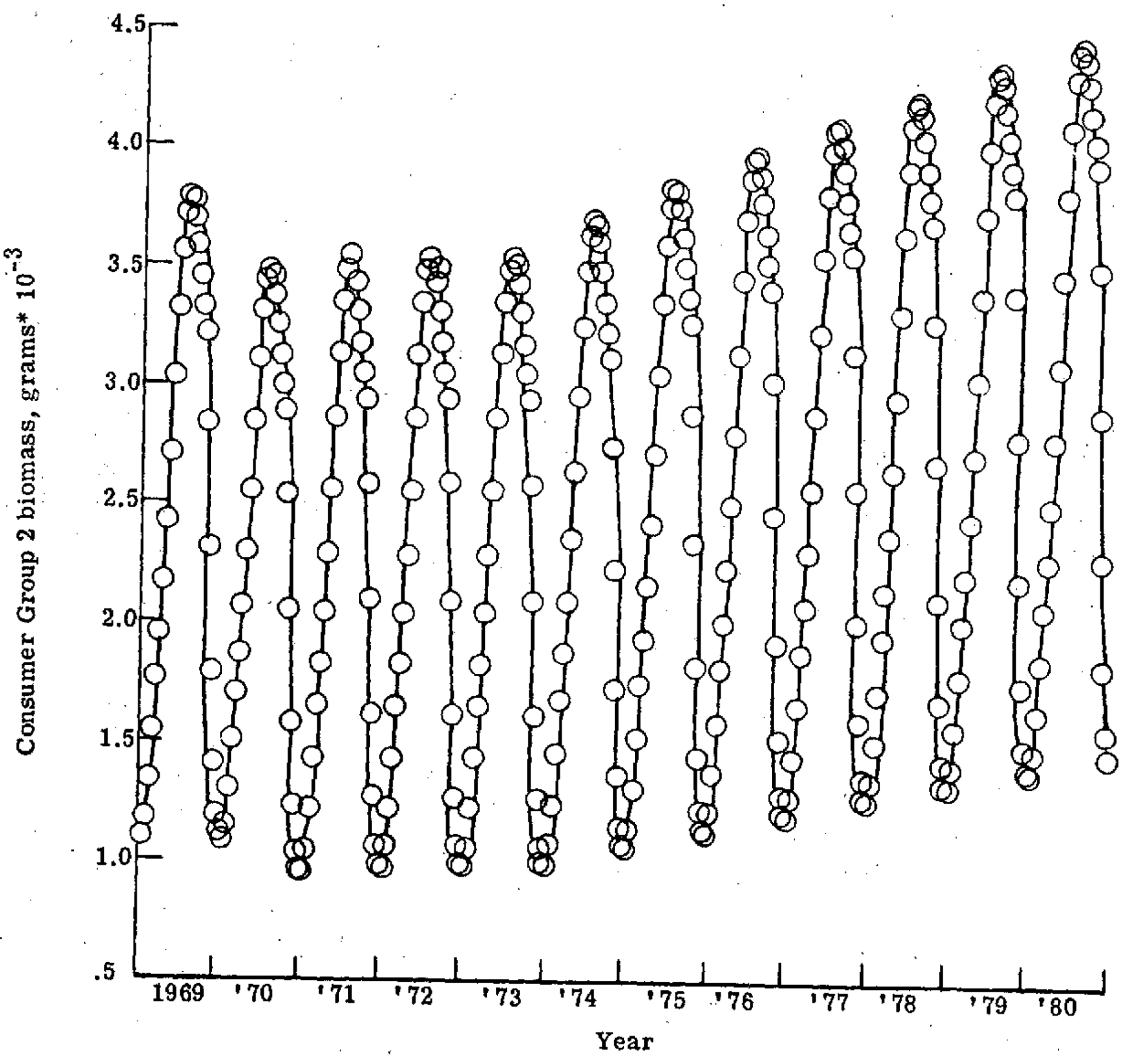

Figure 20.- Herbivores standing crops during period of increased freshwater flow.

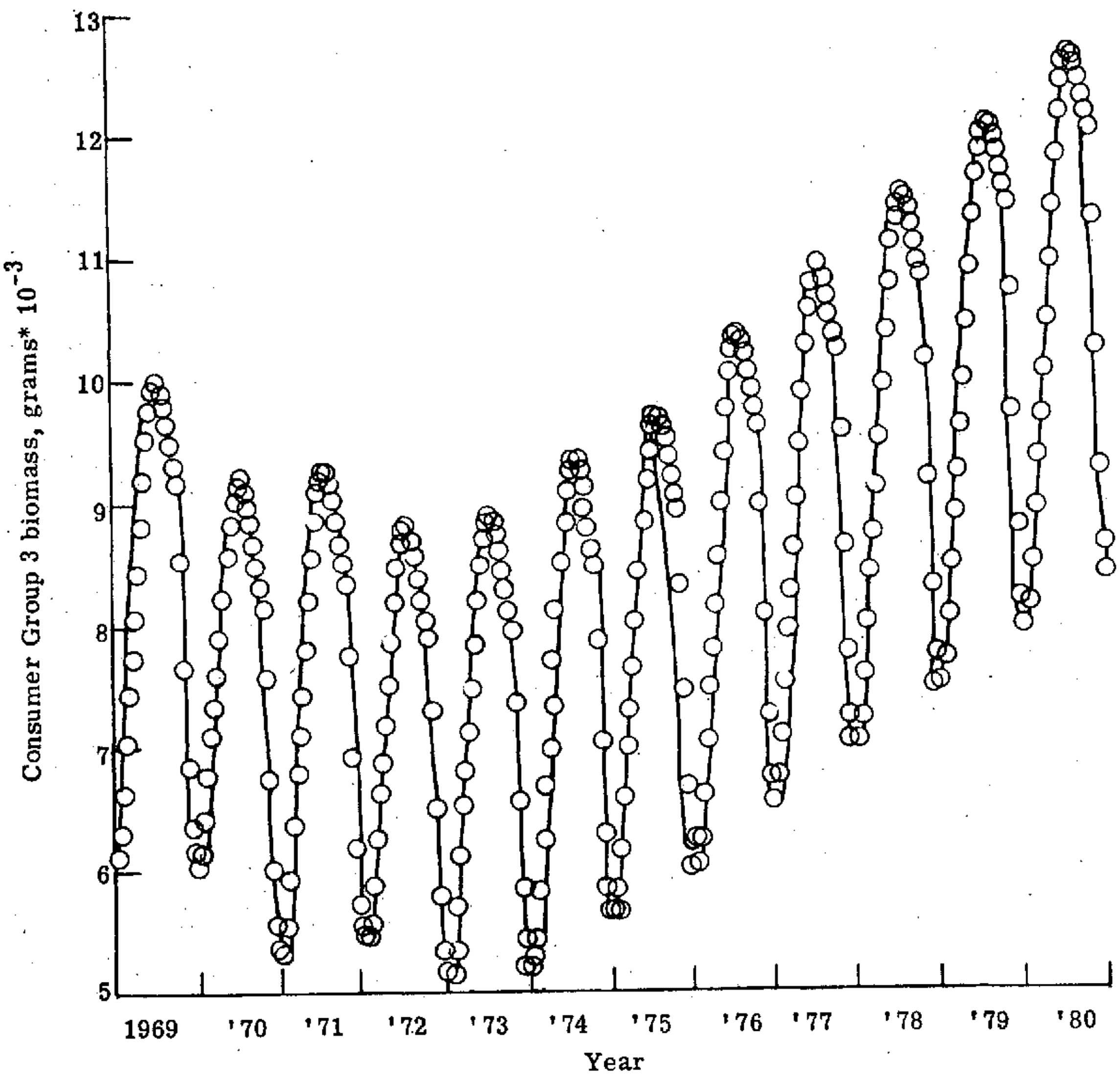

Figure 21.- Omnivores standing crops during period of increased freshwater inflow.

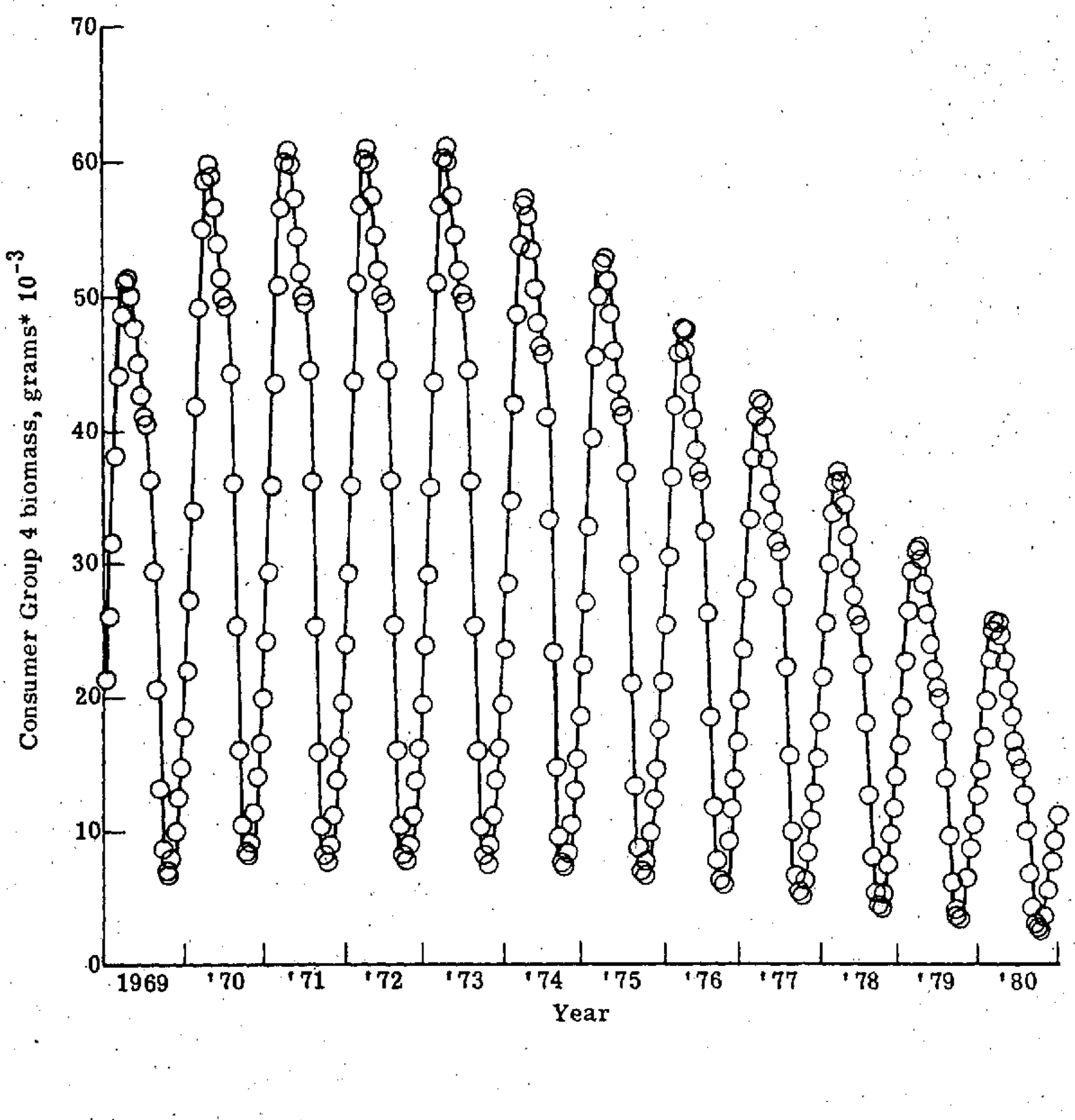

Figure 22.- Primary carnivore standing crops during period of increased freshwater inflow.

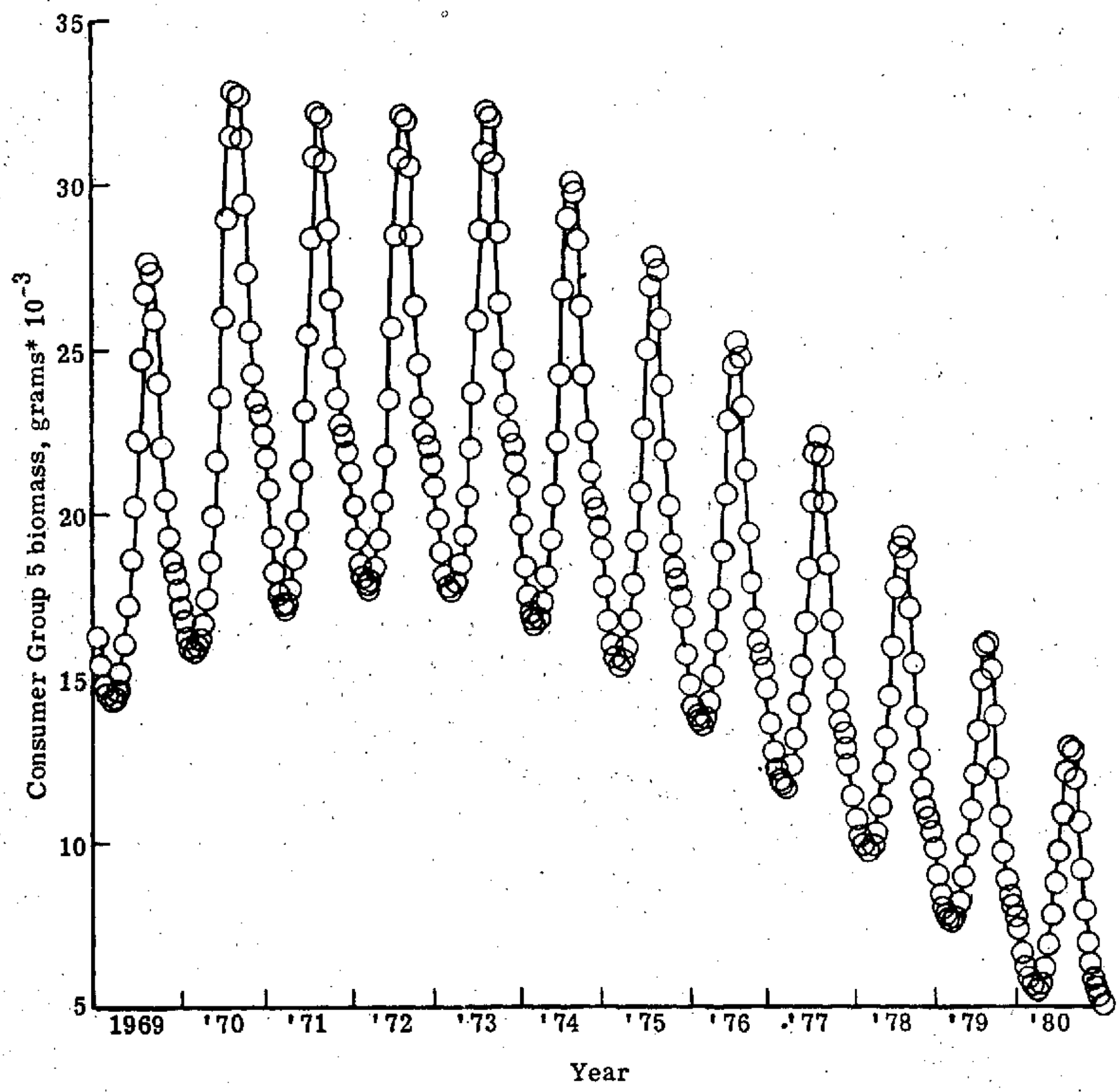

Figure 23.- Middle carnivore standing crops during period of increased freshwater inflow.

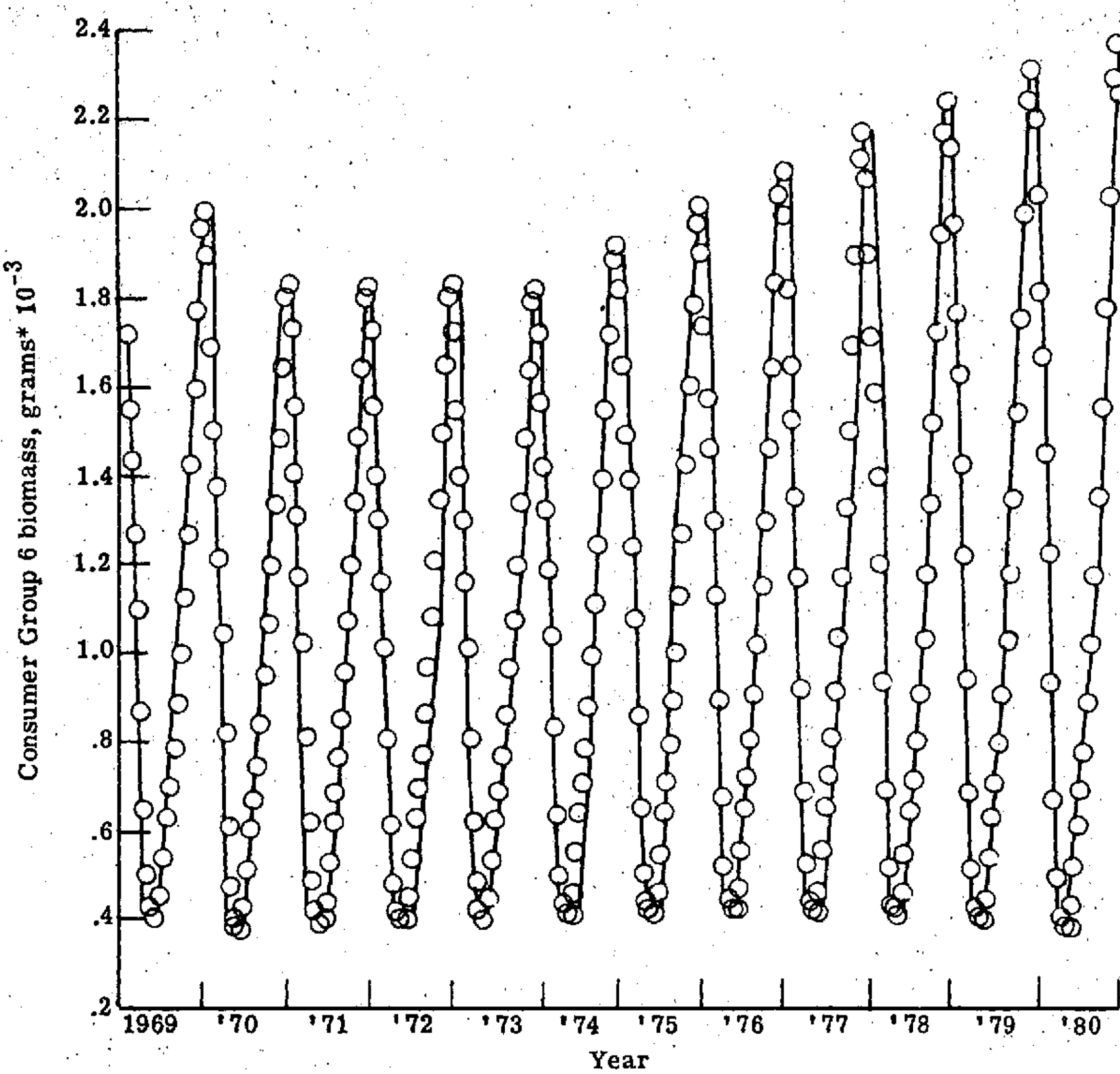

Figure 24.- Top carnivore standing crops during period of increased freshwater inflow.

Model Validation

Model validation was approached by two independent methods; first, a ratio of food consumed to that available in the estuary for each food that is also a consumer, and second, predicting by the model, effects of changes and comparing predicted results to those reported from analogous field studies.

For the ratio of food (consumer group) biomass consumed to that available in the estuary a 10% biomass conversion factor was used (Pendleton 1973) (e.g., weight increase of the consumers was 10% of the food consumed). For the base-line year (1969) ratios were

Food No./Type	Food Consumed[(1)]/Food Available
4./Zooplankton	$1.08 * 10^{0}$
5./Herbivores	$1.13 * 10^{2}$
6./Omnivores	$1.71 * 10$
7./Primary Consumer	$1.27 * 10^{-1}$
8./Middle Consumers	$4.79 * 10^{-1}$

(1) Based on .1 food utilization by consumers (Pendleton 1973)

Foods 4, 5, and 6 (zooplankton, herbivores and omnivores) represent groups of organisms on which we have limited knowledge on growth and reproduction rates (zooplankton) and/or incomplete sampling data (herbivores and omnivores) since they include small bottom dwelling worms, amphipods, ostracods, etc. For foods 7 (primary carnivores)

and 8 (middle carnivores) the analysis indicates that quantities equal to 12.7 and 47.9 percent, respectively, are consumed in the estuary. These values appear to be reasonable based on energy flow and feeding relationships in the estuary, figure 5 (Darnell 1958, 1961; Copeland and Fruh, 1970).

The second validation procedure, was to predict through the model, effects of changes in exogenous variables where results of field studies or other analyses could be used for comparison. Two example studies on reduced pollution input and reduced freshwater inflow are presented in the following section. These are of interest for effective management of estuarine ecosystems.

EVALUATION OF EFFECTS OF MANAGEMENT

The model developed in this study is used to study the effects of changes in exogenous variables, specifically:

a) decrease in waste discharge to the Galveston Bay from the Houston Ship channel (HSC) and

b) changes in freshwater inflow.

Waste Discharge

Armstrong (1973) indicated that due to pollution control measures on the Houston Ship Channel (HSC), projected decreases in pollution load from this source were:

Average 1969-71	153.2×10^6 lb BOD/yr
1973	41.6×10^6 lb BOD/yr
Goal (1975)	29.1×10^6 lb BOD/yr

Effects of this pollution load reduction were evaluated by the model based on the following yearly pollution loads:

Organic Carbon 10^6 lb BOD/yr

Year	Trinity River	HSC	Other	Total
1969 (base-line)	29.9	165.0	52.2	247.1
1970	29.9	152.2	52.2	235.3
1971	29.9	140.0	52.2	222.1
1972	29.9	80.0	52.2	162.1
1973	29.9	41.6	52.2	123.7
1974	29.9	33.0	52.2	115.1
1975	29.9	29.0	52.2	112.1

Freshwater inflow was unchanged as were waste discharges from other sources.

Total productivity in the Galveston Bay is projected to increase by about 40% due to the waste discharge decreases, figure 25. This effect is due to the overall increased basic foods (detritus and phytoplankton) and decreased pollution toxicity effects on organism's growth. As has been discussed previously, total productivity is determined primarily by the primary and middle carnivores (consumer groups 4 & 5, respectively); however, the other consumer groups also increase in productivity, figure 26. Omnivores (primarily shrimp) increased relatively more (67% over base-line year productivity) than the total; due to higher overall sensitivity to pollution effects in their own growth rates and of their food sources. Yearly productivity values for the six consumer groups along with the pollution parameter (average annual total nitrogen) are listed in table III.

Biomass standing crop values in the Galveston Bay during the 7 year period of the analysis are shown in figures 27 through 32. As would be anticipated from the productivity figures (measured by total emigration from the ecosystem) there is a steady increase in biomass standing crop from year to year as pollution input is decreased.

Freshwater Inflow

After the pollution load decrease from the Houston Ship Channel, which was assumed to occur from 1969 through 1975, (see previous example, para. 1), a step decrease of 50% in freshwater discharge from the

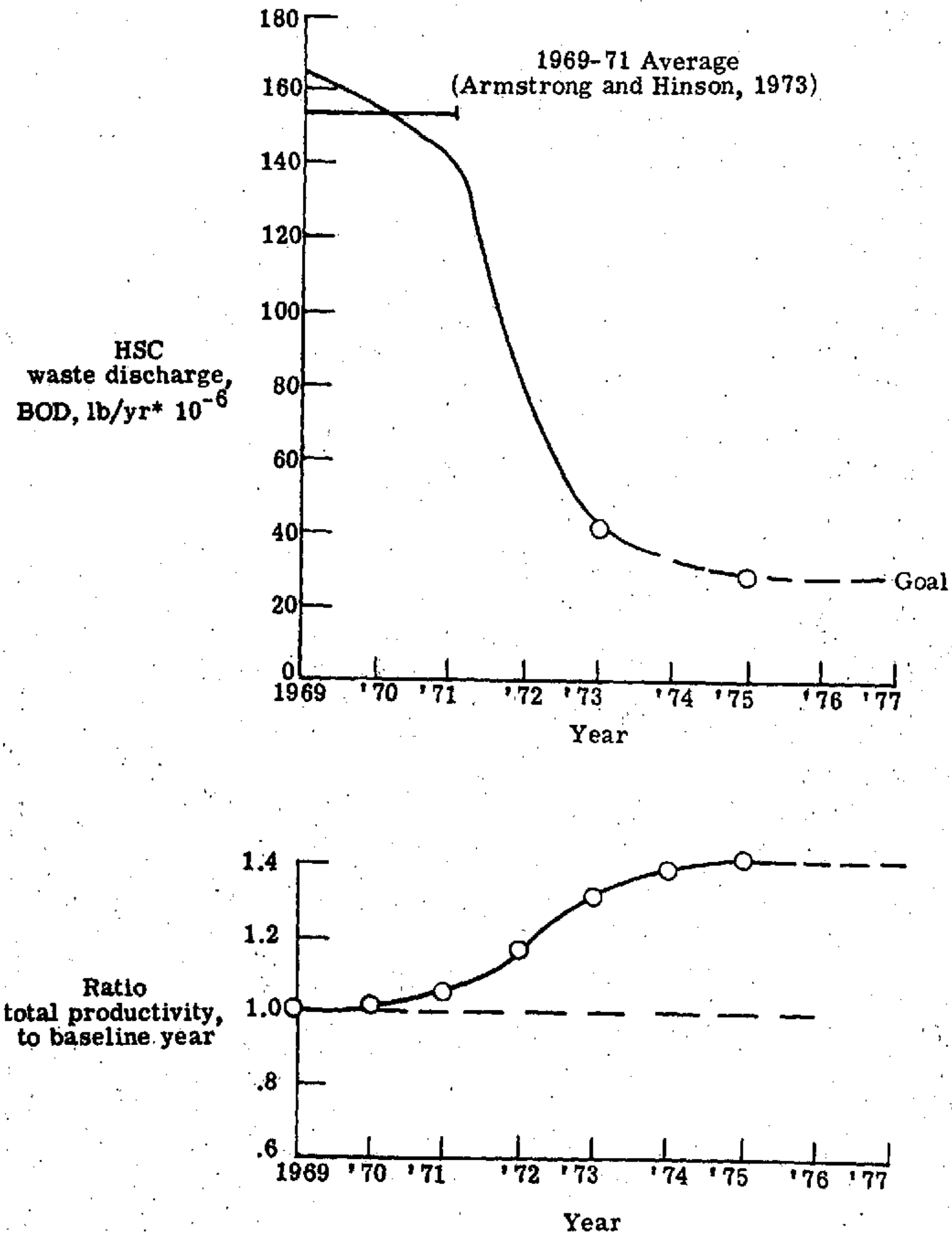

Figure 25.- Projected HSC pollution load and effect on Galveston Bay productivity.

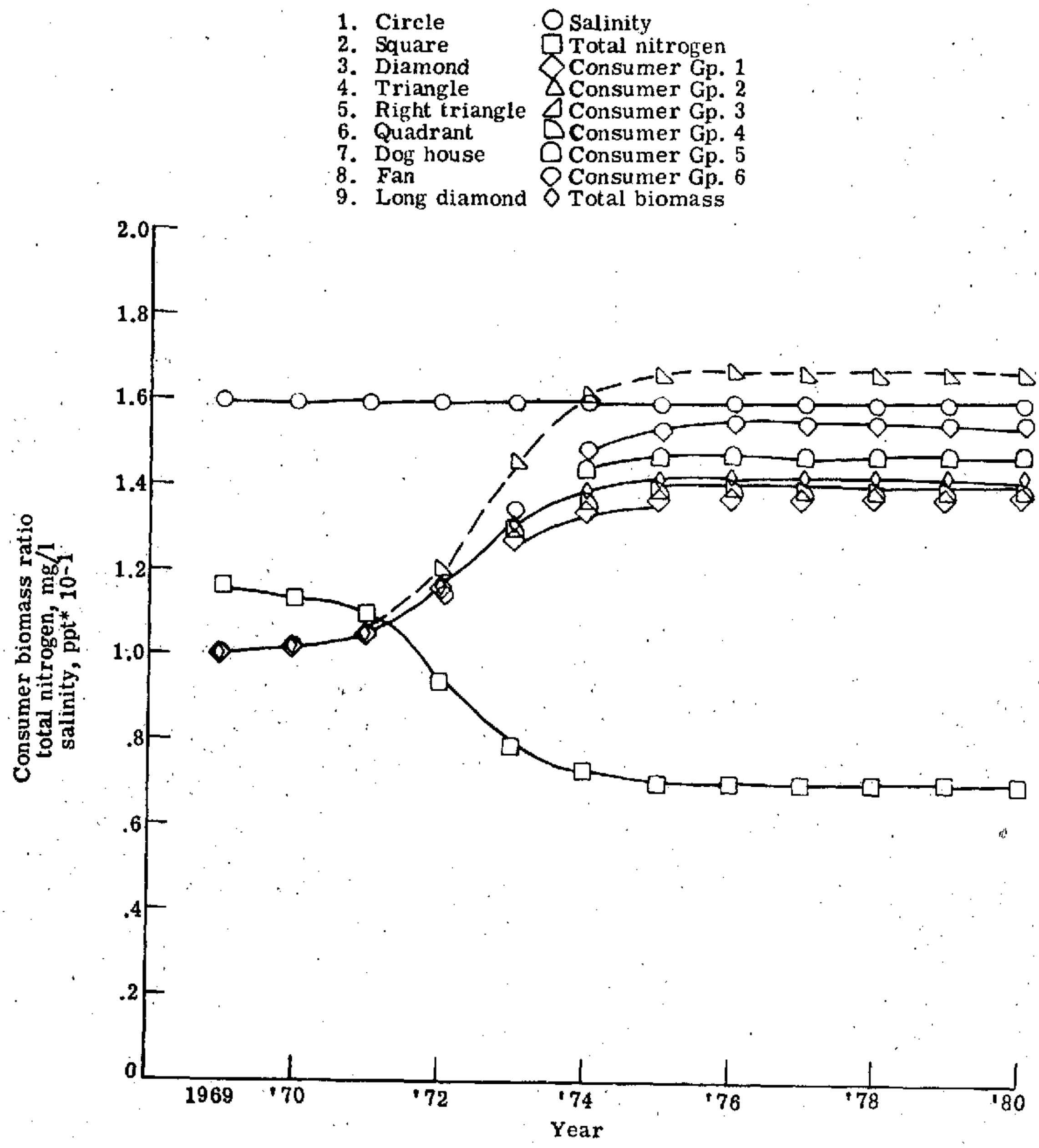

Figure 26.- Galveston Bay productivity ratios for six consumer groups and total biomass due to decreased waste discharge to the Houston Ship Channel.

Table III: Consumer group and total productivity in Galveston Bay as a result of decreased waste discharge to the Houston Ship Channel.

Year		Freshwater Inflow 1000's cfs	Waste BOD, lb/yr $* 10^{-6}$	Salinity, ppt.	Total Nitrogen, mg/l
(1969)	1	1.89E+01	2.47E+02	1.59E+01	1.16E+00
	2	1.99E+01	2.35E+02	1.59E+01	1.13E+00
	3	1.89E+01	2.22E+02	1.59E+01	1.10E+00
	4	1.89E+01	1.62E+02	1.59E+01	9.36E-01
	5	1.89E+01	1.24E+02	1.59E+01	7.83E-01
	6	1.89E+01	1.15E+02	1.59E+01	7.28E-01
	7	1.89E+01	1.12E+02	1.59E+01	6.99E-01
	8	1.89E+01	1.12E+02	1.59E+01	6.99E-01
	9	1.89E+01	1.12E+02	1.59E+01	6.99E-01
	10	1.89E+01	1.12E+02	1.59E+01	6.99E-01
	11	1.89E+01	1.12E+02	1.59E+01	6.99E-01
	12	1.89E+01	1.12E+02	1.59E+01	6.99E-01

Year		Relative Consumer Group Emigration, grams						
		1*	2	3	4	5	6	Total
(1969)	1	9.33E+05	5.02E+03	6.87E+03	9.87E+04	3.08E+04	2.42E+03	1.44E+05
	2	9.47E+05	5.11E+03	6.99E+03	1.01E+05	3.12E+04	2.44E+03	1.46E+05
	3	9.70E+05	5.25E+03	7.31E+03	1.03E+05	3.22E+04	2.53E+03	1.51E+05
	4	1.06E+06	5.82E+03	8.22E+03	1.15E+05	3.50E+04	2.75E+03	1.67E+05
	5	1.18E+06	6.51E+03	9.97E+03	1.28E+05	4.08E+04	3.24E+03	1.89E+05
	6	1.25E+06	6.83E+03	1.11E+04	1.34E+05	4.44E+04	3.58E+03	2.00E+05
	7	1.28E+06	6.95E+03	1.14E+04	1.37E+05	4.51E+04	3.70E+03	2.04E+05
	8	1.28E+06	6.96E+03	1.14E+04	1.37E+05	4.53E+04	3.74E+03	2.04E+05
	9	1.28E+06	6.95E+03	1.14E+04	1.37E+05	4.51E+04	3.73E+03	2.04E+05
	10	1.28E+06	6.95E+03	1.14E+04	1.37E+05	4.51E+04	3.73E+03	2.04E+05
	11	1.28E+06	6.95E+03	1.14E+04	1.37E+05	4.51E+04	3.73E+03	2.04E+05
	12	1.28E+06	6.95E+03	1.14E+04	1.37E+05	4.51E+04	3.73E+03	2.04E+05

*Number

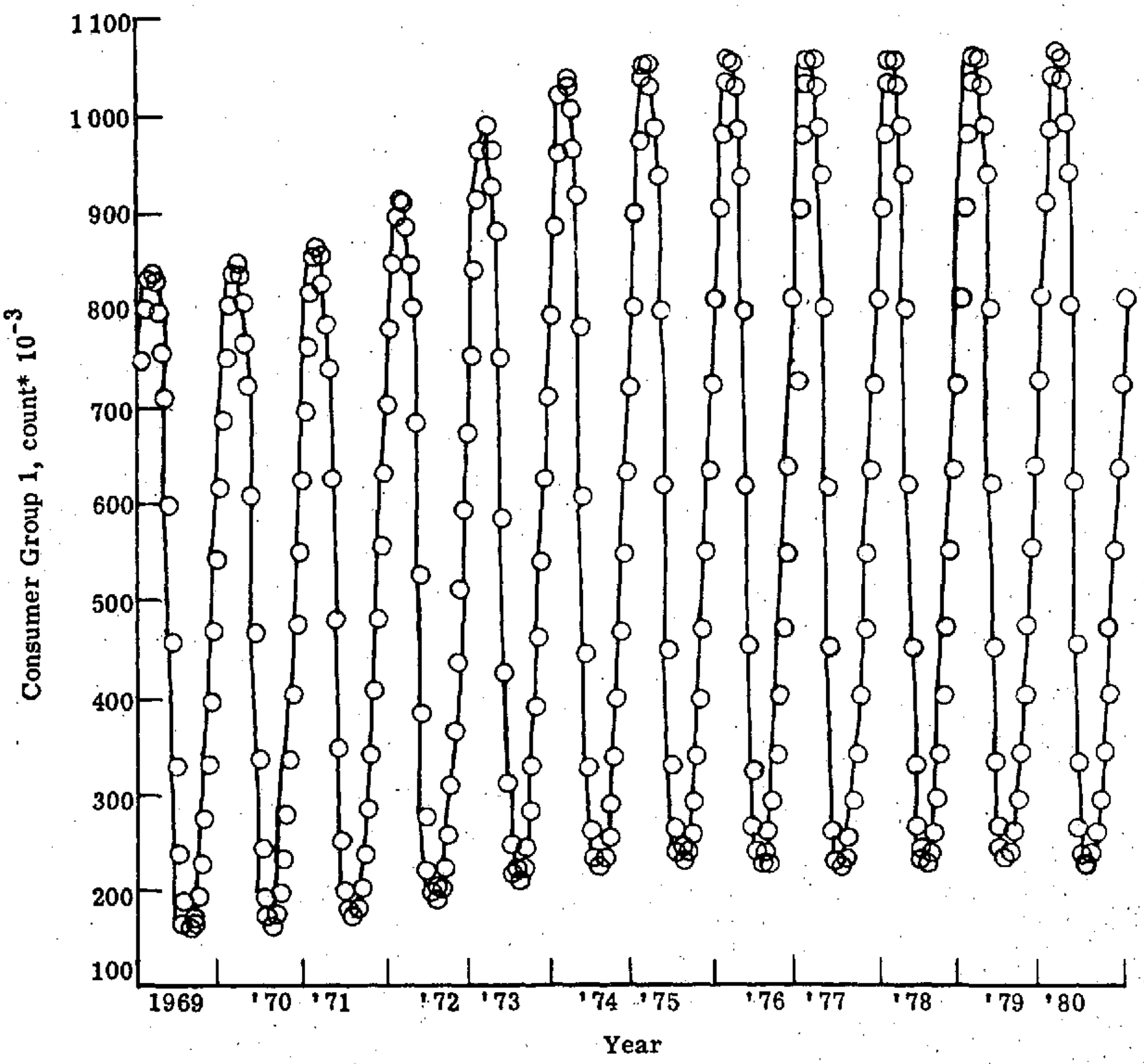

Figure 27.- Zooplankton standing crops during period of decreased waste discharge to HSC.

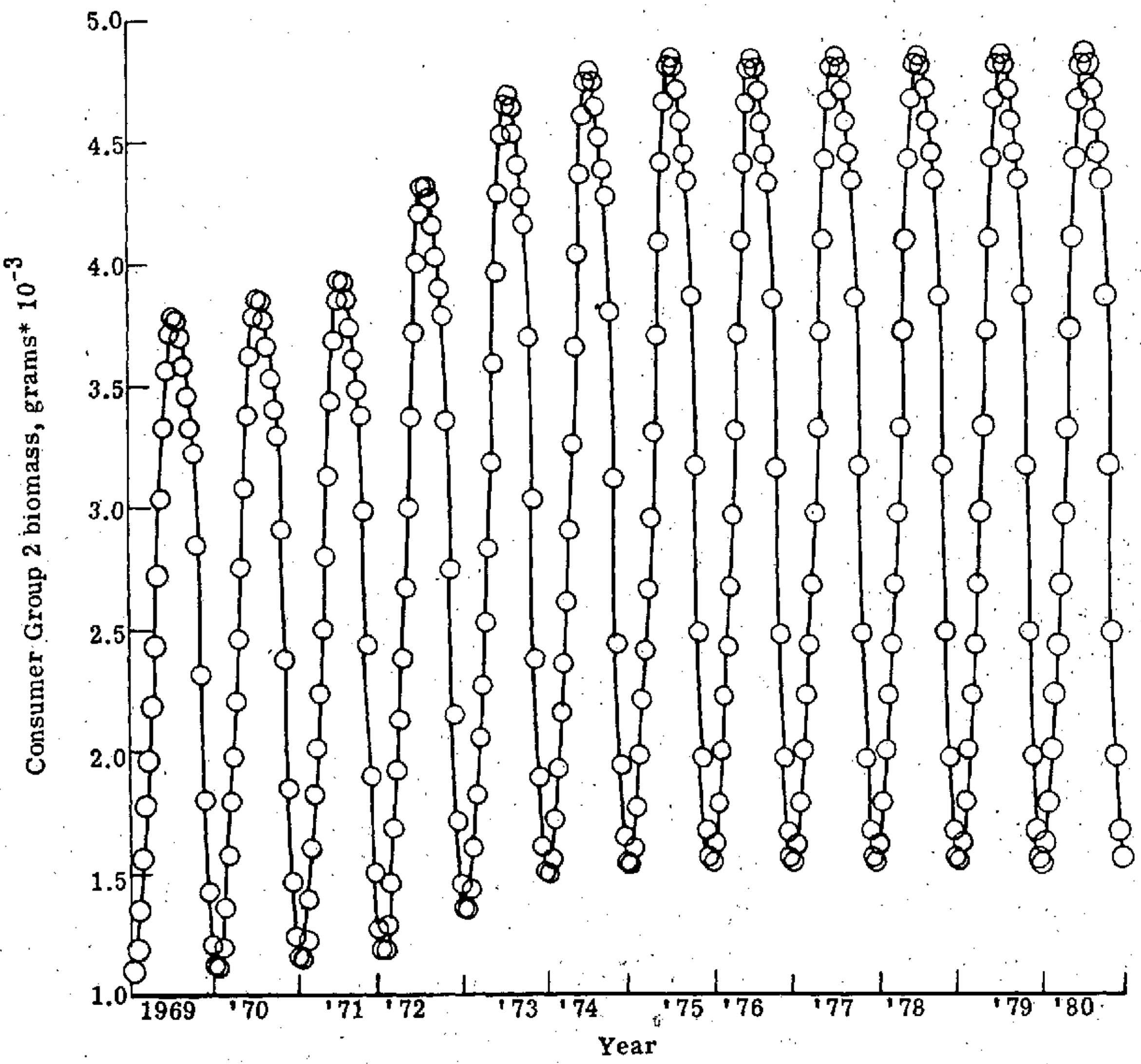

Figure 28.- Herbivore standing crops during period of decreased waste discharge to HSC.

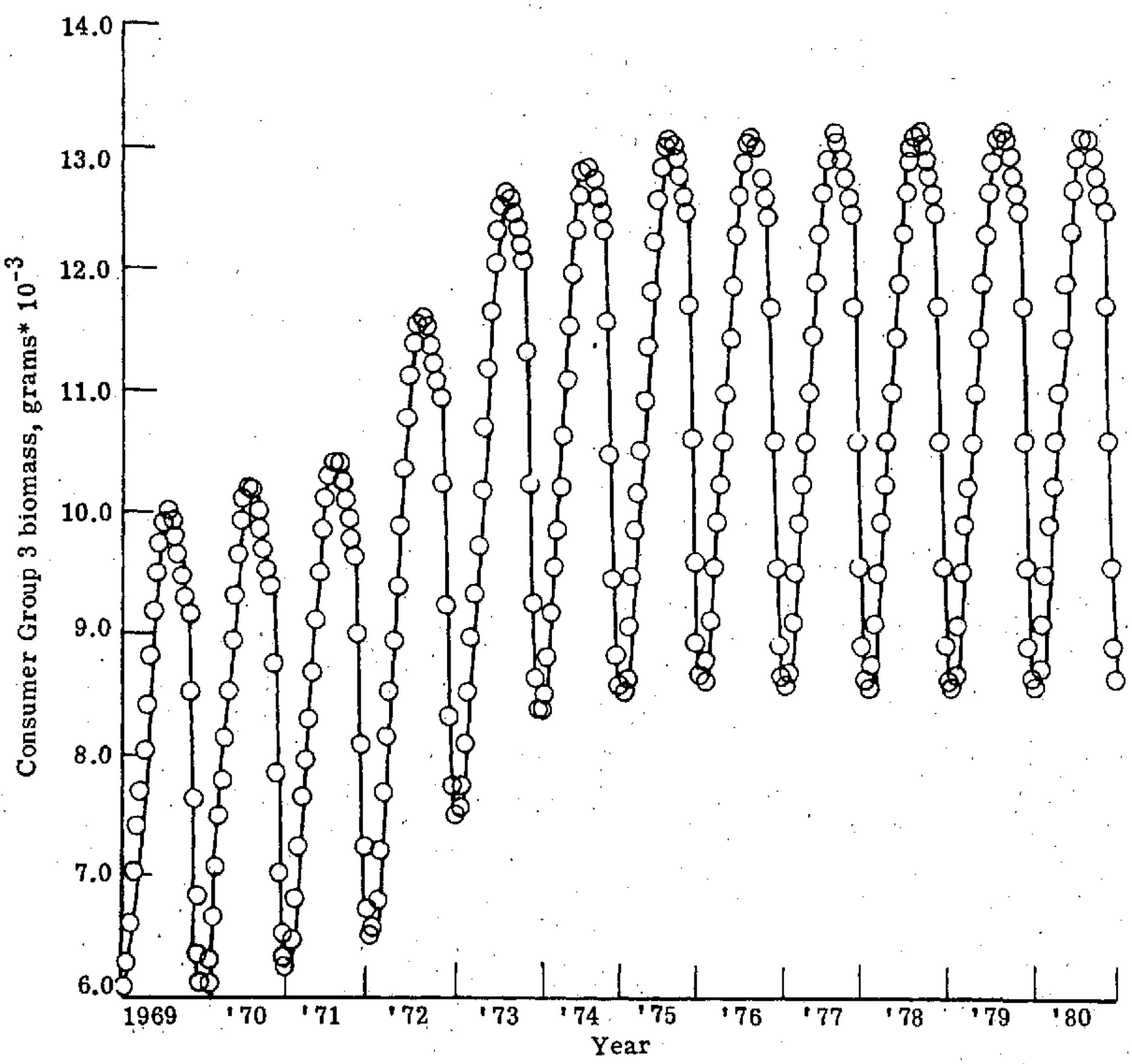

Figure 29.- Omnivore standing crops during period of decreased waste discharge to HSC.

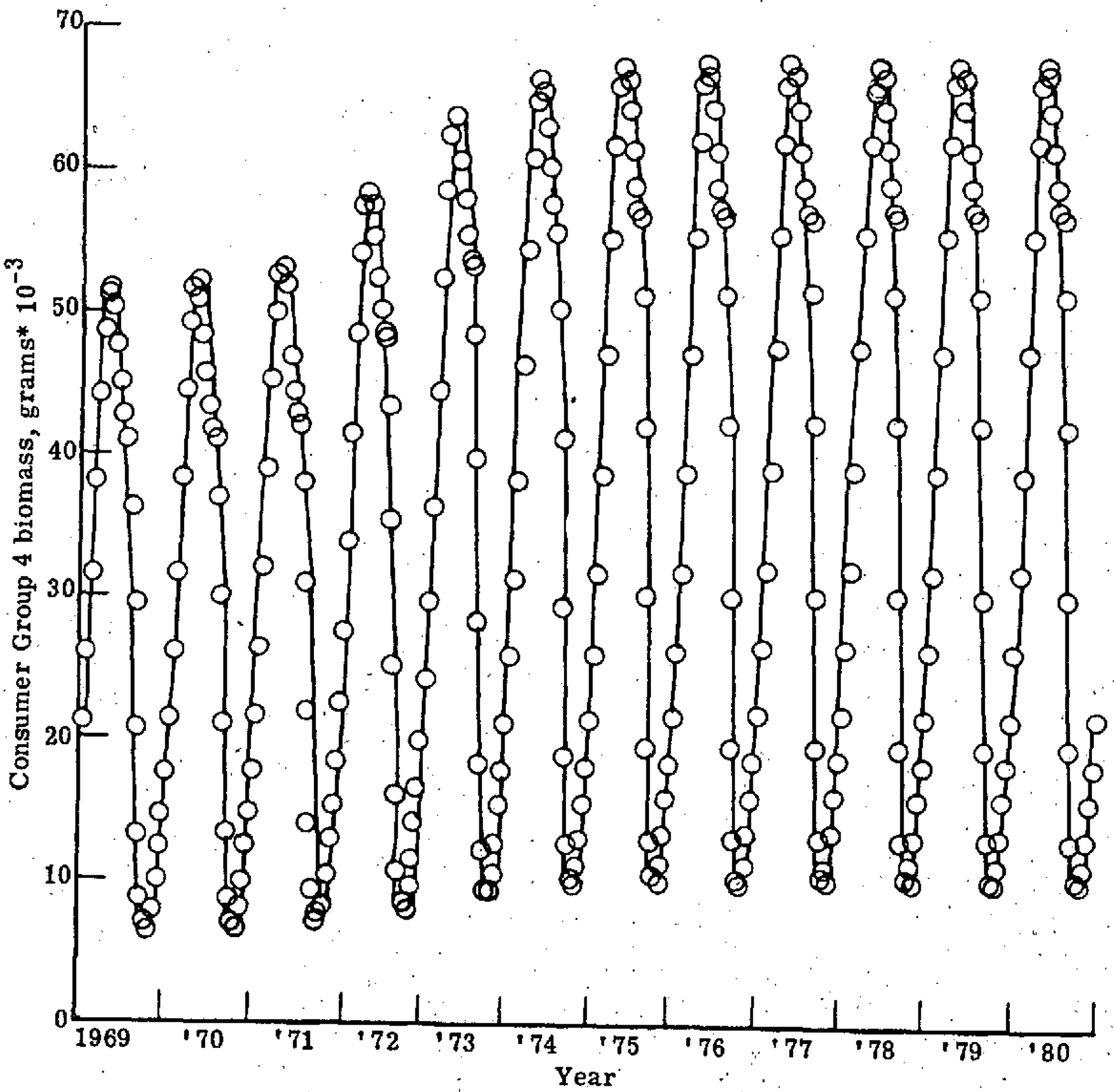

Figure 30.- Primary carnivore standing crops during period of reduced waste discharge to HSC.

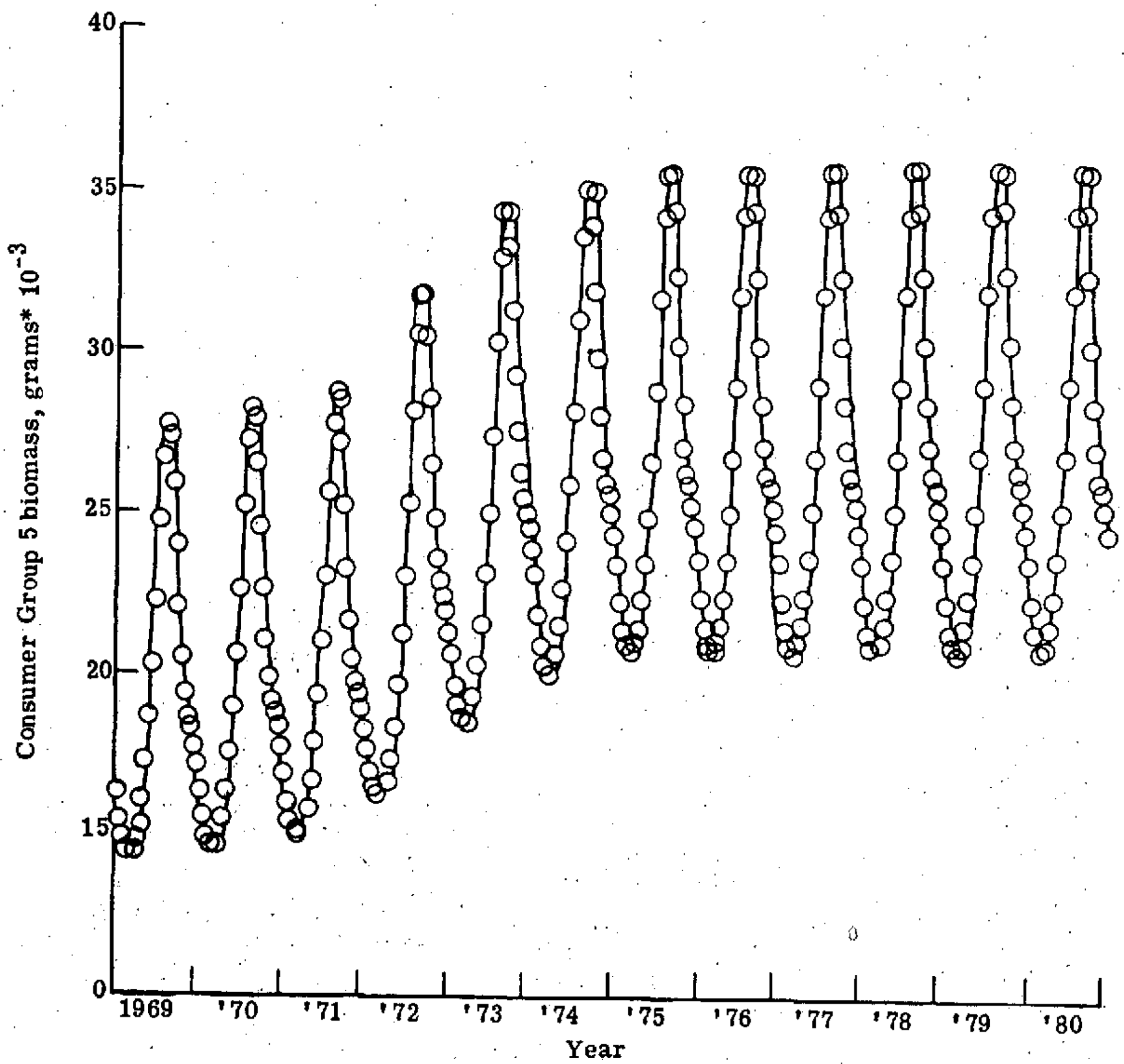

Figure 31.- Middle carnivore standing crops during period of reduced waste discharge to HSC.

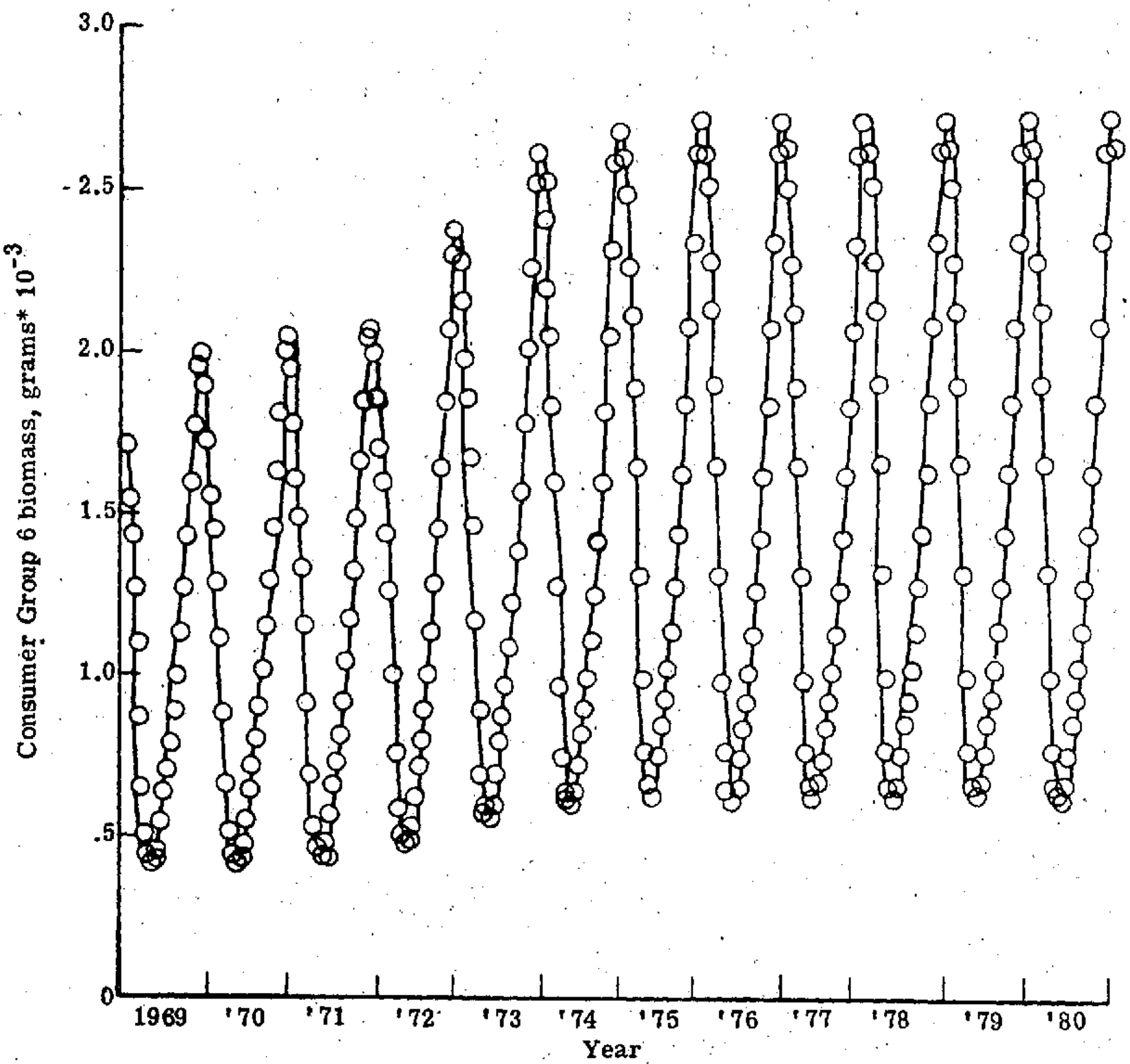

Figure 32.- Top carnivore standing crops during period of reduced waste discharge to HSC.

Trinity River (e.g., due to filling a reservoir) was assumed for the calendar year 1976, followed by a restoration to 75% for the calendar year 1977 and three following years. Freshwater inputs to the Galveston Bay were then:

Freshwater Inflow, 1000 CFS

Year	Trinity River	HSC	Other	Total
1969-1975	5.58	10.53	2.79	18.90
1976	2.79	10.53	2.79	16.11
1977	4.18	10.53	2.79	17.50
1978-1980	4.18	10.53	2.79	17.50

Total productivity in the Galveston Bay ecosystem increased about 50% above the base-line year due to the combined effects of reduced waste discharge to the Houston Ship Channel, followed by reduced Trinity River freshwater discharge, figure 33 and table IV. Effects due to the first change (reduced waste discharge) are discussed in the previous section. Reduced freshwater flow leads to increased total productivity; however, one of the commercially important consumer groups (omnivores, which includes the shrimp species) is reduced about 20%, due to their sensitivity to system changes (salinity and pollution concentrations). The middle carnivores (consumer group 5 which includes the anchovy) are favorably affected (increased about 18%) due to decreased freshwater and the consequent increase in salinity. The other consumer group productivities are moderately increased (about 10%)

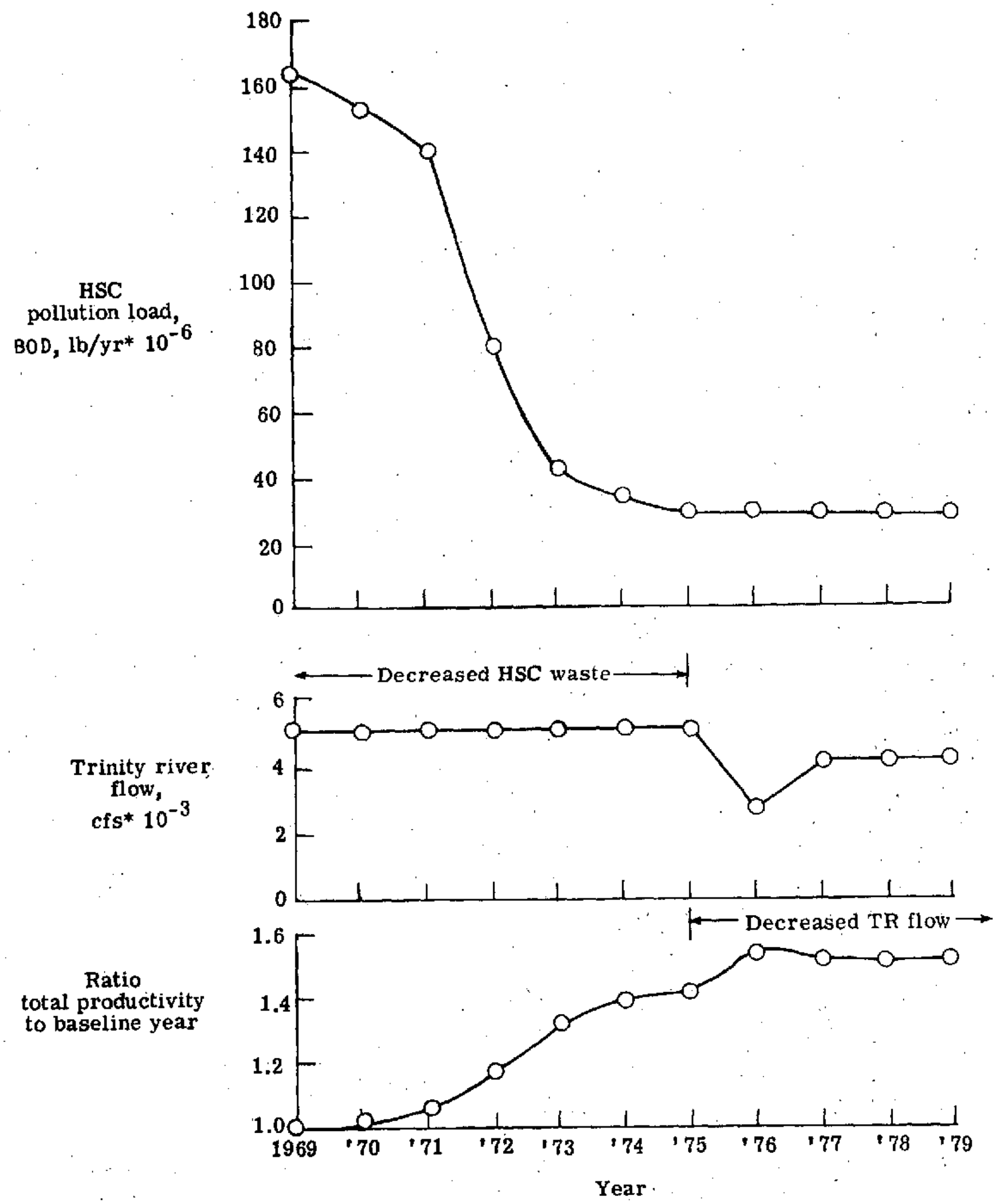

Figure 33.- Effect on Galveston Bay productivity due to Decreased HSC Pollution load (1969-1975) followed by decreased Trinity River freshwater discharge (1976-1980).

Table IV: Consumer group and total productivity in Galveston Bay as a result of decreased waste discharge (in the HSC) followed by decreased freshwater flow from the Trinity River.

Year		Freshwater Inflow cfs* 10^{-3}	Waste BOD, lb/yr * 10^{-6}	Salinity, ppt.	Total Nitrogen, mg/1
(1969)	1	1.89E+01	2.47E+02	1.59E+01	1.16E+00
	2	1.89E+01	2.35E+02	1.59E+01	1.13E+00
	3	1.89E+01	2.22E+02	1.59E+01	1.10E+00
	4	1.89E+01	1.62E+02	1.59E+01	9.36E-01
	5	1.89E+01	1.24E+02	1.59E+01	7.83E-01
	6	1.89E+01	1.15E+02	1.59E+01	7.28E-01
	7	1.89E+01	1.12E+02	1.59E+01	6.99E-01
	8	1.61E+01	1.12E+02	1.70E+01	7.68E-01
	9	1.75E+01	1.12E+02	1.64E+01	7.28E-01
	10	1.75E+01	1.12E+02	1.64E+01	7.28E-01
	11	1.75E+01	1.12E+02	1.64E+01	7.28E-01
	12	1.75E+01	1.12E+02	1.64E+01	7.28E-01

Year		Relative Consumer Group Emigration, grams						
		1*	2	3	4	5	6	Total
(1969)	1	9.33E+05	5.02E+03	6.87E+03	9.87E+04	3.08E+04	2.42E+03	1.44E+05
	2	9.47E+05	5.11E+03	6.99E+03	1.01E+05	3.12E+04	2.44E+03	1.46E+05
	3	9.70E+05	5.25E+03	7.31E+03	1.03E+05	3.22E+04	2.53E+03	1.51E+05
	4	1.06E+06	5.82E+03	8.22E+03	1.15E+05	3.50E+04	2.75E+03	1.67E+05
	5	1.18E+06	6.51E+03	9.97E+03	1.28E+05	4.08E+04	3.24E+03	1.89E+05
	6	1.25E+06	6.83E+03	1.11E+04	1.34E+05	4.44E+04	3.58E+03	2.00E+05
	7	1.28E+06	6.95E+03	1.14E+04	1.37E+05	4.51E+04	3.70E+03	2.04E+05
	8	1.49E+06	6.73E+03	1.11E+04	1.60E+05	5.02E+04	3.68E+03	2.32E+05
	9	1.46E+06	6.78E+03	1.08E+04	1.51E+05	5.38E+04	3.63E+03	2.26E+05
	10	1.40E+06	6.86E+03	1.09E+04	1.49E+05	5.00E+04	3.68E+03	2.20E+05
	11	1.41E+06	6.84E+03	1.07E+04	1.49E+05	4.95E+04	3.66E+03	2.20E+05
	12	1.41E+06	6.84E+03	1.10E+04	1.49E+05	4.97E+04	3.67E+03	2.20E+05

*Number

by the decreased flow. Productivity ratios (ratios of current year to baseline year) for the six consumer groups and average annual salinity and total nitrogen concentrations are shown in figure 34. It is interesting to note the carry-over effects in the ecosystem predicted by the model. For example, there is a strong perturbation on consumer group 3 (omnivores) due to effects from prior years. The specific reason for this lag is unknown and may be due to reproduction or food effects, but has been well documented in previous studies (Copeland 1966). The significant idea however is that short term (year to year) comparisons may be misleading where management of an ecosystem is concerned.

From an estuarine fisheries viewpoint, biomass levels within the Bay are important since they represent concentrations available for harvest (catching) at a given time. Biomass levels for each of the six consumer groups over the period for the assumed conditions are shown in figures 35 through 40. Zooplankton density increased in 1976 and 1977 due to decreased freshwater inflow. Subsequently, short term effects of increased foods and increased pollution appear to offset each other, with a subsequent stabilizing at a lower level. As indicated from the productivity analysis the omnivores (consumer group 3) are the most sensitive to system changes. There is a sharp decrease in biomass levels of these consumers followed by relatively rapid stabilization at a value about 10% below the point before freshwater inflow was decreased. Consumer group biomass levels tend to shift about due to delayed responses in growth of foods within the estuary, then stabilize at the new level after about 2 years. One of the factors that must be

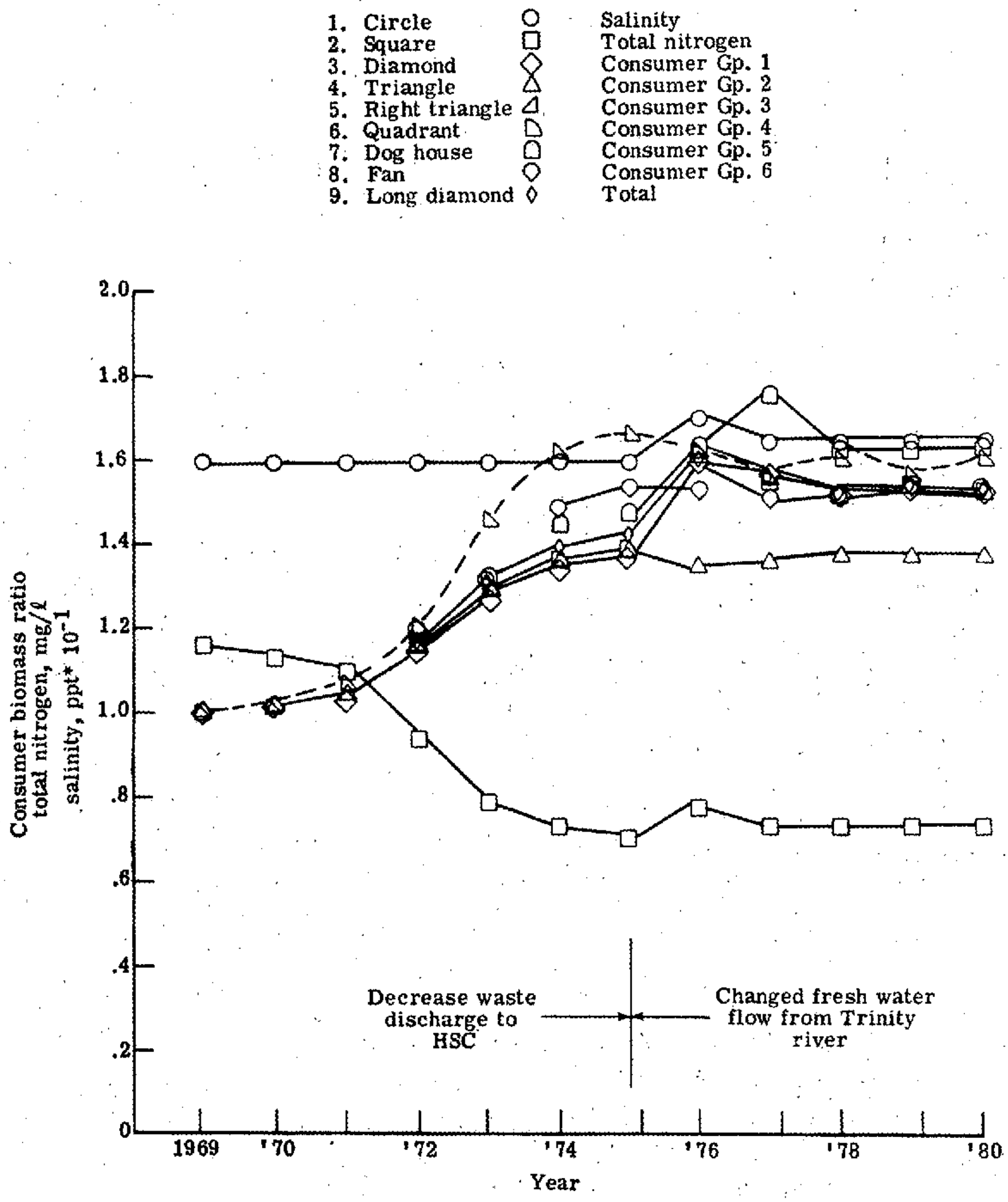

Figure 34.- Productivity as result of decreased pollution and decreased freshwater inflow.

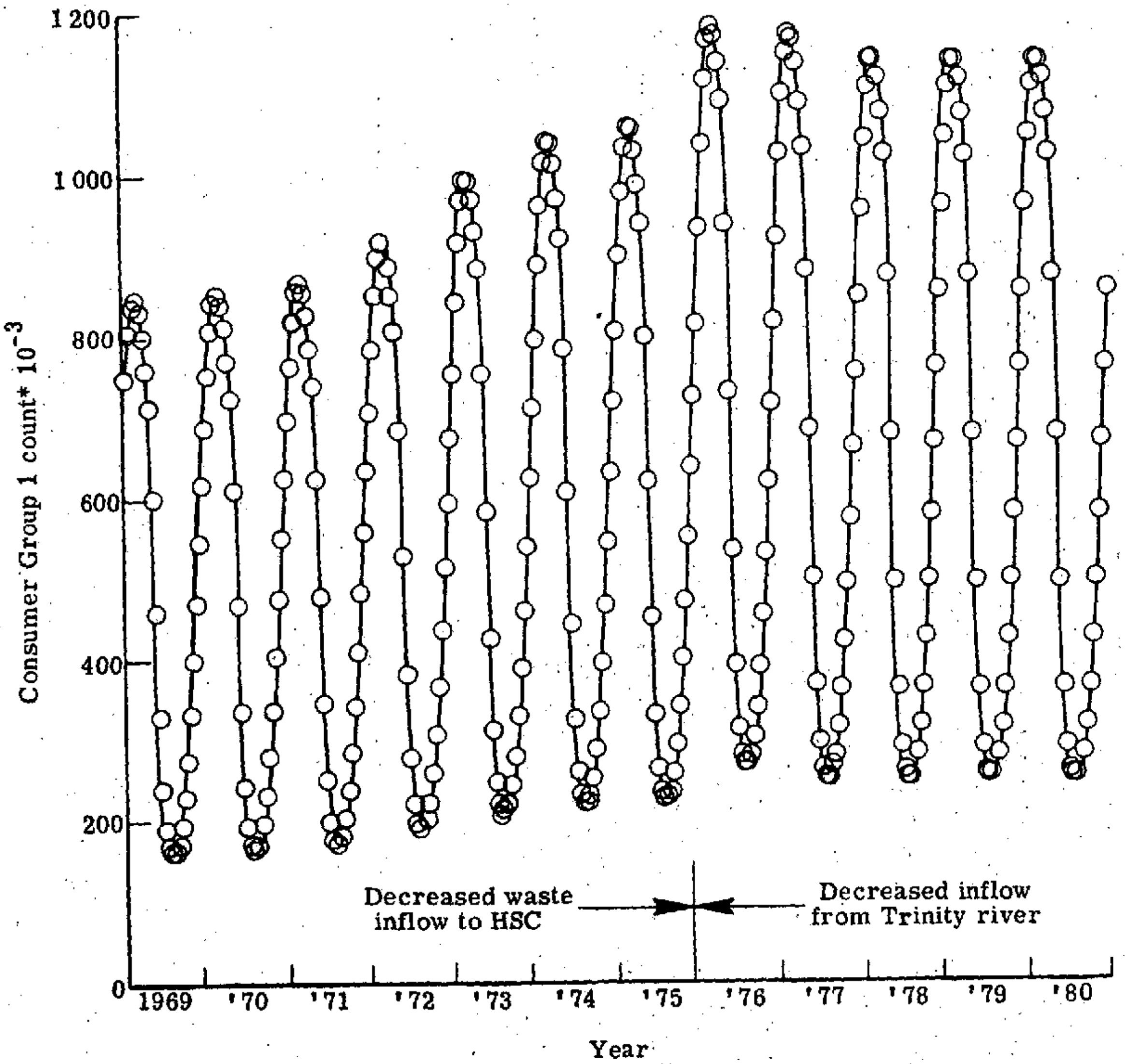

Figure 35.- Zooplankton standing crops due to decreased pollution and decreased freshwater inflow.

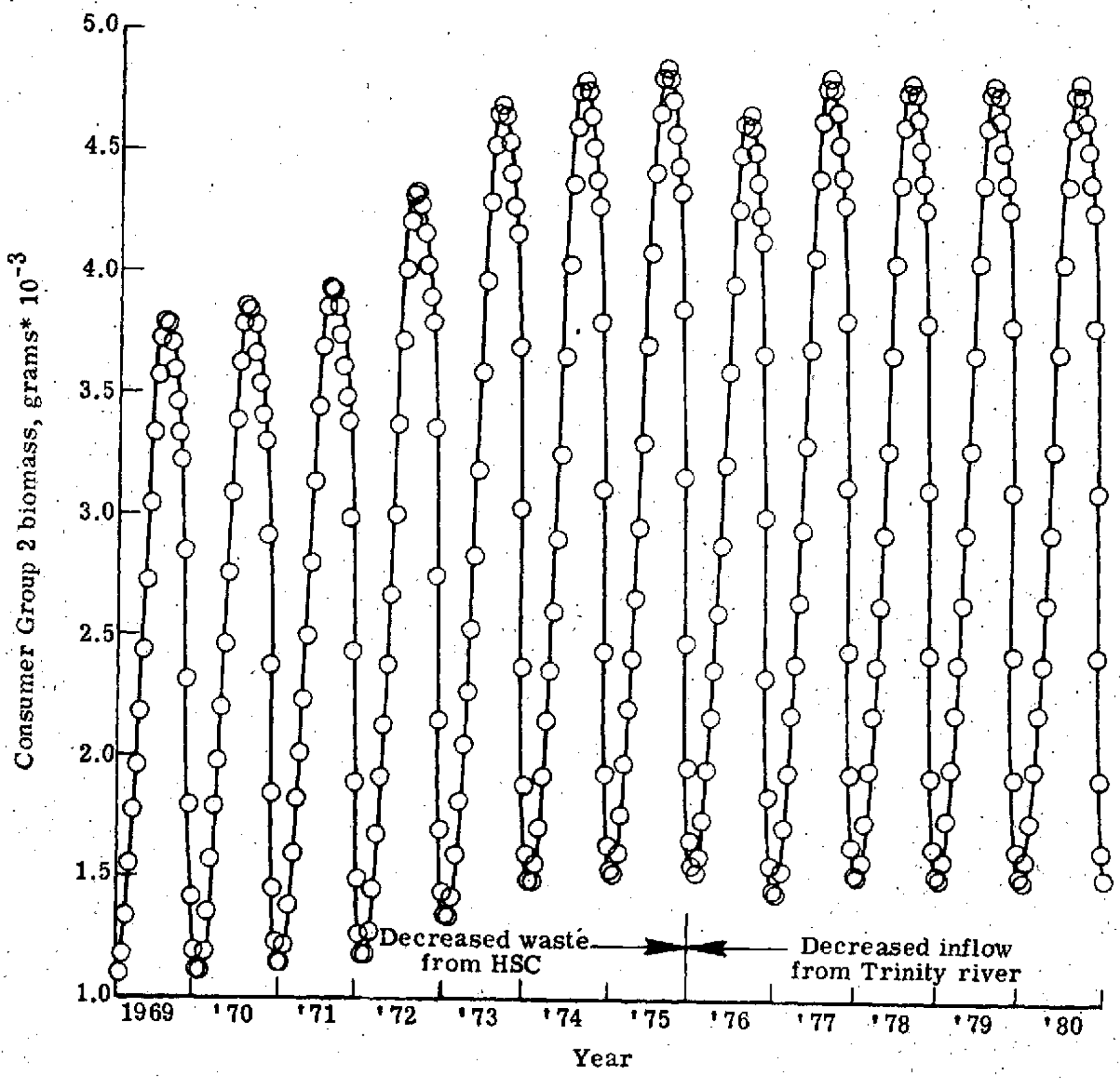

Figure 36.- Herbivore standing crops due to decreased pollution and decreased freshwater inflow.

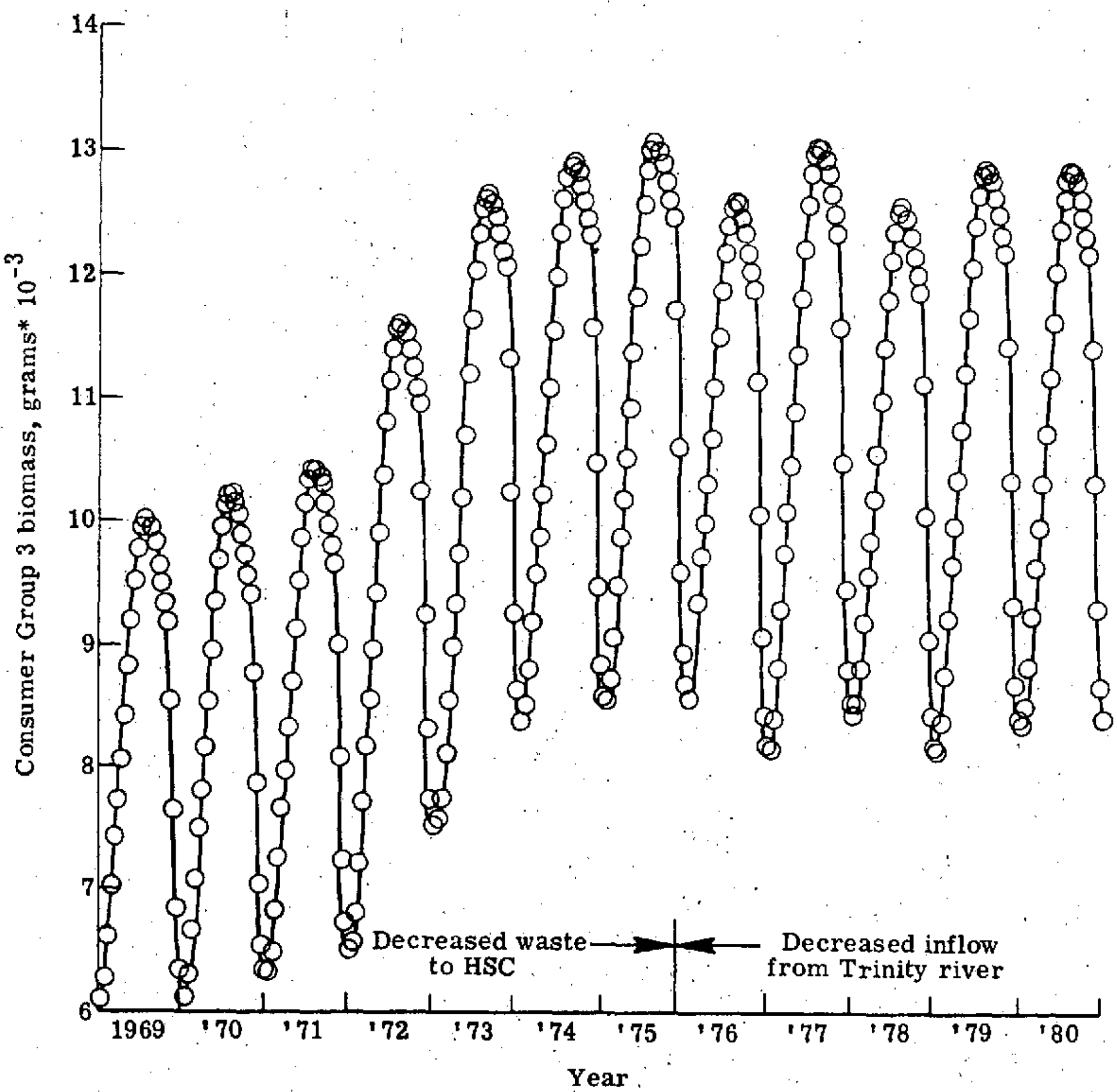

Figure 37.- Omnivore standing crops due to decreased pollution and decreased freshwater inflow.

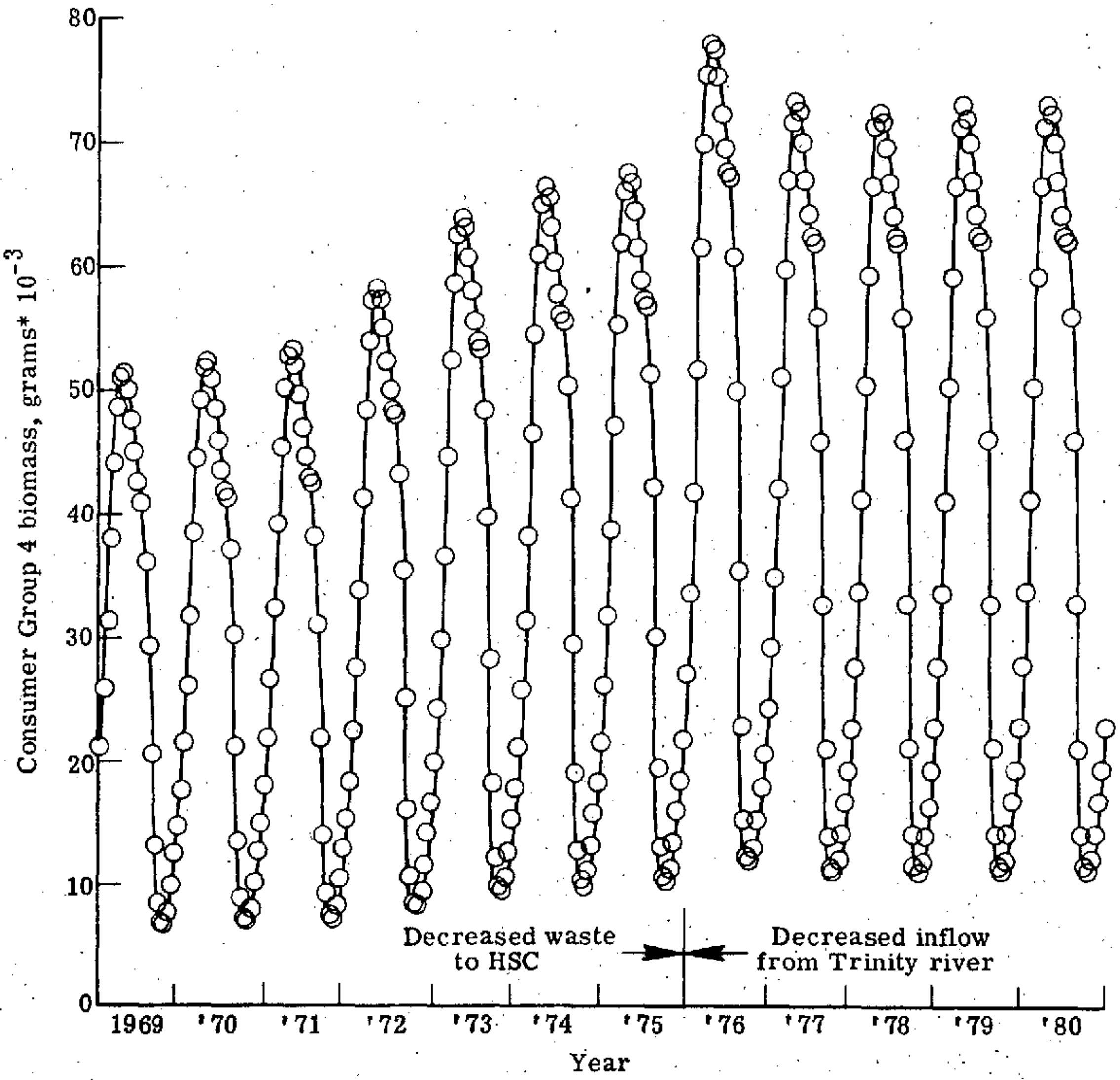

Figure 38.- Primary carnivore standing crops due to decreased pollution and decreased freshwater inflow.

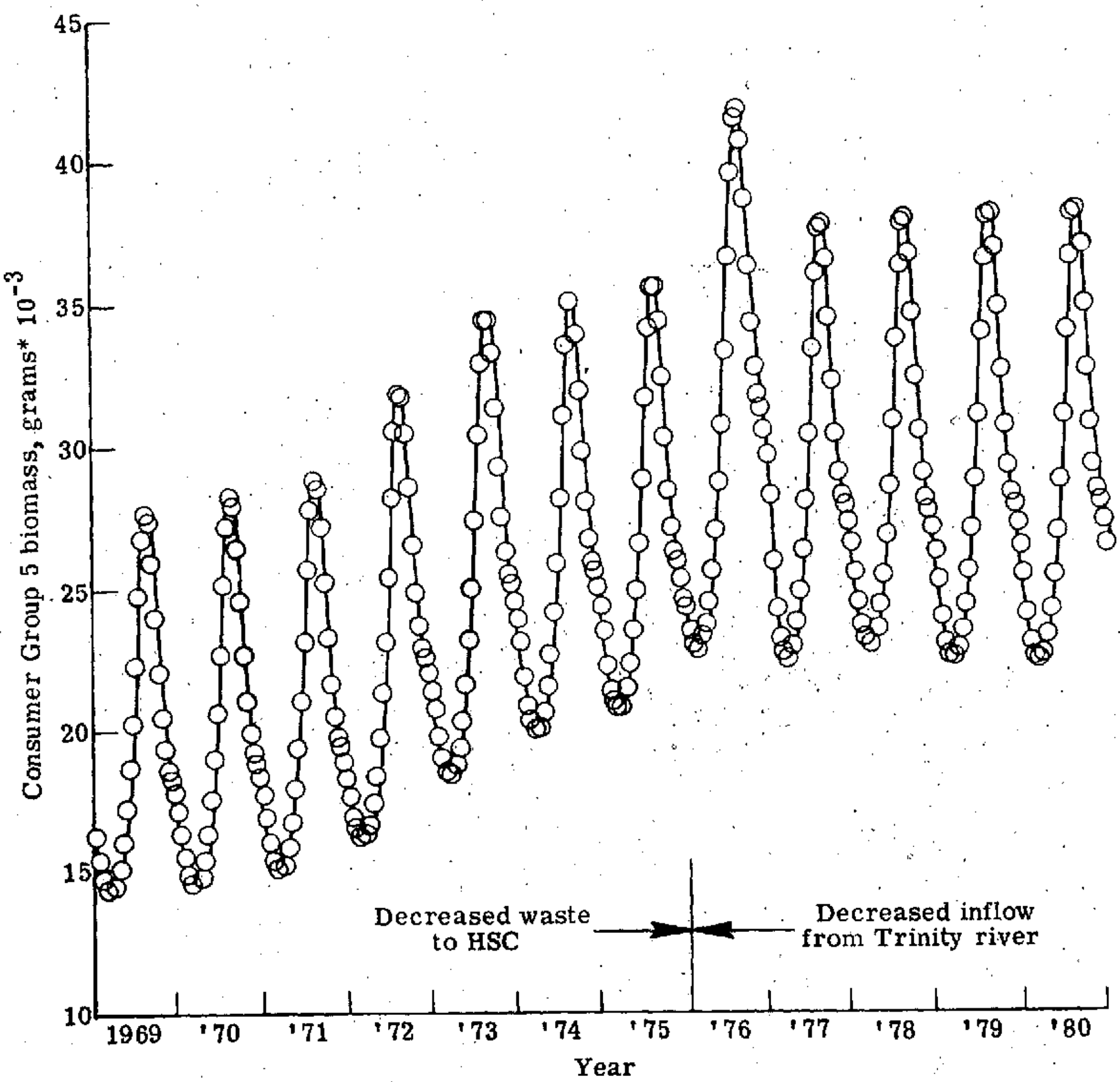

Figure 39.- Middle carnivore standing crops due to decreased pollution and decreased freshwater inflow.

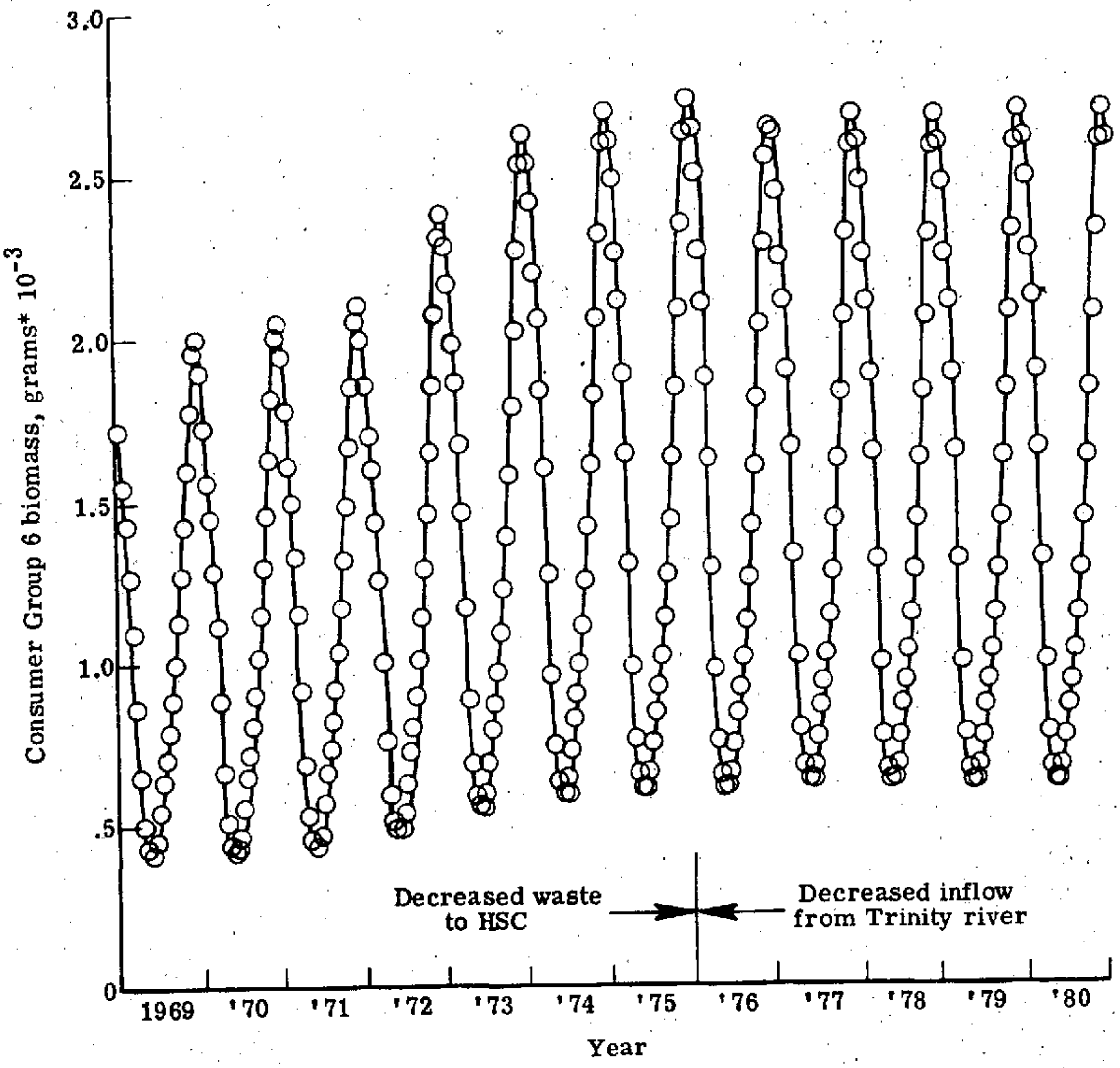

Figure 40.- Top carnivore standing crops due to decreased pollution and decreased freshwater inflow.

taken into consideration, of course, is that year to year effects are not completely understood and thus possible effects have been minimized in the model due to lack of quantitative data.

DISCUSSION AND RECOMMENDATIONS

A simulation type mathematical model that quantitatively relates the chemical, physical and biological characteristics of an ecosystem has been developed for the Galveston Bay, Texas. The model incorporates results of a number of investigations into detailed processes in the ecosystem including those of seasonal immigration and emigration, food and consumer densities, feeding habits and responses of organisms to exogenous changes such as waste discharge and freshwater inflow.

Two examples of possible management actions are analyzed using the model. Comparison of model predictions and results from analagous field studies over a 20 year period and reported in the literature demonstrate the model's usefulness. The first example evaluates the effects of reduced pollution inflow from the Houston Ship Channel. Increased overall productivity with relatively higher increases for shrimp is in agreement with Copeland (1966), Armstrong and Hinson (1973) and Wohlschlag (1972). The second example investigated the effects of reduced freshwater inflow. Predicted results of increased zooplankton and finfish and decreased shrimp are in agreement with Copeland (1966), Cooper (1967), and Armstrong and Hinson (1973). Additional advantages of the model, of course, are quantification of the results and more complete analysis of time-dependent (system lag) effects.

One of the purposes of the effort was to develop a model that may be used to provide predictive information to those responsible for estuarine management. To the extent that a quantitative relationship

has been developed and verified (at least with historical data) this basic objective has been accomplished. The degree that those quantitative relationships are used will be determined by the confidence and subsequent use for inputs to management action. Obviously, determining the degree to which this has been successfully accomplished is beyond the scope of this particular effort.

One factor apparent from this modeling effort of ecosystems is the general lack of in-depth studies of the multi-parameter effects of seasonality, food, temperature, pollution, environment, etc. on the survival and growth of estuarine species. Laboratory studies have been made in some cases of the better known and/or commercially important species; however, due to various limitations these have seldom been extended to the ecosystem level and when they have, with limited consideration of more than one variable; the others held constant, ignored, or assumed of secondary significance.

In this study, only those variables subject to control and consequently important in management decisions are classed as primary variables (e.g., freshwater inflow, waste-discharge and their distribution in the ecosystem). It is probably important to know the effects of such variables as temperature (to assess power plant locations, for example) but its significance as a management tool may be limited, particularly if its control is beyond the scope of management. (On the other hand, knowledge of these effects may be necessary to develop a model with adequate predictive accuracy for power plant siting studies, etc.)

In the present study emphasis has been placed on ecosystem response, as opposed to detailed responses within the ecosystem (e.g., of specific species). Thus, foods and consumers were grouped on the bases of function rather than studies of individual species of plants and/or organisms. This has many advantages from the modeling viewpoint, but obviously leads to problems for the biologist, since his groupings may not be the same and/or there are interactions within or outside of the group that are not compatible with laboratory investigations. On the other hand, it is obviously necessary to know more about the ecosystem than relationships such as ... "when freshwater input increases, shrimp catches increase two years later". The missing information is a quantitative description of the links in the energy flow over the two year period. For example, what ecosystem processes are affected during the delay? Are these due to hatching and spawning, immigration, food availability, predator-prey relationships, etc? In addition, each of these quantitative relations must be compatible with interlocking processes in the ecosystem. Thus, in theory, an analytical description of an ecosystem is an almost infinite number of simultaneous equations.

With some background and experience in assessment of ecosystem response it is possible to quantify <u>some</u> of the more significant relationships. This is the basis of this modeling effort. From additional studies of the model the critical parameters may be determined and these should be the basis for further studies to improve our understanding and predictive capability of the model.

As a result of this modeling effort which uses analyses and data from previous studies, additional data are required in the following areas:

1. Affect of pollutants on survival and growth of dominant estuarine species;
2. Absolute or relative effects of pollutants on different food and consumer species in an estuarine ecosystem;
3. The degree and extent of variations in immigration and emigra- from year to year; and
4. Quantitative definition of observed biological time delays such as the approximate two year lag in shrimp productivity after changes in freshwater inflow.

The list is only limited by the accuracy requirements of the modeling processes; that is, the objectives of the program.

It is recommended that the simulation model which includes analytical and empirical descriptions of Galveston Bay ecosystem processes be used where possible to predict effects due to exogenous changes in freshwater inflow, waste discharges, and other system parameters. When results of later studies become available these should be incorporated. Further, the modeling and ecosystem processes concepts developed in this study should be applied to other ecosystems, whether they are subject to natural or man-influenced exogenous effects.

CONCLUSIONS

As a result of this investigation and analysis of the results the following conclusions are made:

1. A simulation type mathematical model has been developed for the Galveston Bay, Texas, ecosystem that quantitatively relates pollution and freshwater inflow to secondary productivity.
2. Ecosystem responses for two potential management actions, reduced pollution input and changes in freshwater inflow, were evaluated and results may be studied by management to determine the desireability of such actions.
3. Outputs of the model are quantitatively applicable to the Galveston Bay. In the same temperate zone (approximately same latitude and weather conditions) the model is readily adaptable to other ecosystems. Initial numerical results should be reviewed carefully for local effects.
4. For other temperate zones and/or different environmental (rainfall, tides, etc.) conditions a study must be made to determine similarity among consumers, food types and availability, and seasonal growth characteristics between the Galveston Bay and the ecosystem of interest. Calibration and model verification will probably require a comprehensive sampling effort in addition to historical systems responses (sampling or commercial catch records in conjunction with rainfall, for example).

5. Development of a reliable predictive model is an iterative process that improves with iterations; the systems analysis model provides an optimized framework for analysis using all available information.

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APPENDICES

APPENDIX A

Functional characteristics of the Galveston Bay model are described in the model section. Consumer group biomass values are developed in two basic steps. First, productivity (biomass) curves for the baseline year (1969) use well-established ecosystem characteristics (e.g., immigration, growth and emigration) to determine, by iterative techniques, model constants. The basic objective is reasonable agreement between the model biomass curve and sampled data, figures 14 and 15. Second, for years after the baseline, biomass growth rate is the product of the prior year's net growth rate and growth rate ratios (of the current to prior year) due to changes in

1) food and consumer densities;
2) environmental factors (including pollution); and
3) distribution.

Equations explicitly describing the above functions are discussed in the following sections.

Baseline year

Baseline year biomass curves explicitly describe sample values and biological factors in model language. The pertinent ecosystem factors (e.g., immigration, growth and emigration) are shown schematically in Figure 14. Reference will be made to curves "a" through "e". Model baseline year constants for consumer group 4 are listed in the model section. Model equations are expressed in terms of the calendar year periods, I.

Immigration (curve "a") is taken as the positive portion of a sine function (π radians) and is described by the equation

CONSIM(I,L) = SIN(R1(L) * 3.1416/R2(L))* CONSTIM (L) (1)

where

R1(L) = number of periods since start of immigration;

R2(L) = number of periods of immigration; and

CONSTIM (L) = maximum immigration level, grams

(where R1(L) > R2(L), CONSIM (I,L) = 0.)

Larval and post-larval populations have very high growth rates, decreasing with increasing organism size (Patten, 1971; Paloheimo and Dickie, 1965). A decreasing value exponential function is used to describe the growth rate of immigrated consumer groups in the baseline year (adult biomass in the baseline year has a growth rate of 0). The model equation is

*EXPGR (M,L) = ([exp(.05 * (27 - M))] - 1.) * BLYGRL(L) (2)

where

BLYGR = the growth factor for consumer group L in the baseline year.

*GEPYR(I,L,1) in the model when correlated with the calendar year periods.

Period growth rates are determined by this relationship for each consumer group to obtain the baseline year biomass curves. Growth rate multiplier is 1.0 plus growth rate.

After growth in the estuary the consumer organisms emigrate from the ecosystem - in this case primarily to the Gulf of Mexico. In the

model emigration is the sum of two components - early and late emigration.

a. <u>Early emigration</u> EAREM(I,L) - is that phase of emigration which occurs at about the time of the biomass peak of that consumer group and is determined by:

*EAREM(I,L) = SIN(R3(L) 3.1416/R4(L) * FACTEM(L) * YCONSIL(L) (3)

where

R3(L) = No. periods since start of early emigration;

R4(L) = No. periods over which early emigration occurs;

FACTEM(L) = Constant multiplier for consumer group; and

YCONSIL(L) = Biomass of young of consumer group L, grams, for the period of calculation.

(IF R3(L) > R4(L) EAREM(I,L) = 0.)

b. <u>Late emigration</u> (FOREM(I,L) is determined by

*FOREM(I,L) = YCONSIL(L) * (R5(L)/(R6(L) + 1.)) (4)

R5(L) = Periods since start of late emigration

R6(L) = Periods from start of late emigration to end of seasonal year.

(IF R5(M,L) > R6(M,L) FOREM(I,L) = 0)

*In the model the total emigration is CONSEM(I,L)

Numerical values for the constants in the above equations were determined iteratively to provide reasonable fit between model biomass curves and

sampled data. An important step in the baseline year portion of the model is to sequentially correlate the individual consumer group seasonal periods (M) with the calendar year periods (I). Note that in the baseline year portion of the model the consumer group biomass curves are developed independently.

In the model, consumer growth rate multipliers and ratios are designated by the acronym GEPYR (I,L,K) for young (*e.g.*, this years immigration) or GEPAR(I,L,K) for adult biomass where

I = calendar year model periods, I = 1,...,26;

L = consumer group, L = 1,...,6; and

K = sequential number for growth multipliers

K = 1, for baseline or prior year

K = 2, ratio for food and consumer densities;

K = 3, ratio for environment (including pollution);

K = 4, ratio for distribution; and

K = 5, net growth rate current year (product of 1-4 above).

GEPYR (I,L,1) values are determined for the baseline year using values from the exponential curve (In the baseline year all other GEPYR and GEPAR multipliers are equal 1.0). Thus GEPYR(I,L,5) equals GEPYR(I,L,1) and GEPAR(I,L,5) equals 1.0 for the baseline year. In subsequent years GEPYR(I,L,1) for the current year is set equal GEPYR(I,L,5) for the immediately prior year; GEPYR(I,L,K), K = 2,...,4; values are calculated; and GEPYR(I,L,5)for the current year is the product of

GEPYR(I,L,K), K = 1,...,4. Adult growth rate multipliers are determined in an analogous manner.

Predictive Model

After the baseline year, biomass levels in the ecosystem may change due to changes in net growth rates, which result from new values of food and consumer densities and/or exogenous variables. Revised net growth rates (the product of prior year net growth rate and growth rate change ratios) are used to determine current year biomass levels by iterative calculations.

Exogenous variables (inputs) in the model are freshwater inflow and pollution load. The former directly affects only salinity and both variables affect the pollution indicator, total nitrogen (e.g., by dilution or pollution load). Average annual values are used in the model as discussed in Section II. These physical and chemical changes are used to determine revised growth rates due to

1) Food and consumer densities;

2) Environmental factors (including pollution); and

3) Distribution,

which will be discussed in that order.

Food and consumer densities.

Food and consumer density effects on growth were studied by Brocksen, Davis and Warren (1970) in an environment where there was both a distinct consumer and a distinct food. However, in the Galveston Bay ecosystem there are a variety of consumers and a number of foods as

discussed in the ecosystem section. From the feeding preferences of the Galveston Bay consumers energy source matrices were developed from Figures 6 through 11. This figure (41) shows a typical period of a matrix which is 26 (*e.g.*, I) segments deep. There are separate matrices for the young and adult consumers. Note that the columns add to 1.0 since they represent the total energy intake of each consumer group. The purpose is to provide a model-period relationship between consumer food requirements (or desires) and food density. Further, by comparing the current year's consumer group biomass to the prior years, we may assess consumer density effects.

Explicit expressions used to determine food availability, food and consumer densities and resulting growth rate ratios follow (Note that foods 1 through 3 are not affected by consumer group growth rates, but foods 4 through 8 are consumer groups 1 through 5, respectively).

Armstrong & Hinson (1973) estimated that 58% of the detritus organic carbon comes from marsh and other rooted grasses. In this study it is assumed that the above grasses are influenced by the same factors that affect the growth rates of phytoplankton and detritus is from the prior year's growth (Heald, 1973). Freshwater flow rate from the rivers will affect the flushing rate from the marshes and rivers and is accounted for by a .5 power factor on the water flow ratio; which is applied to the remaining 42% of the organic carbon. There are no prior studies in this latter area; however this is not a sensitive factor in model performance.

Detritus for years after the baseline year is determined by:

Food (J),		Consumer Group (L)					
		1	2	3	4	5	6
Detritus and undet organic	1	.1	.7	.5	.3	.1	-
Phyto plankton	2	.9	.1	.1	.1	-	-
Vascular plant mtl	3	-	.1	.1	-	-	-
Zoo- plankton	4	-	.1	.1	-	.2	-
Herbivores	5	-	-	.2	.5	.4	-
Omnivores	6	-	-	-	.1	.3	.1
Primary carnivores	7	-	-	-	-	-	.3
Middle carnivores	8	-	-	-	-	-	.6

Figure 41.- Typical period of Galveston Bay consumer energy source matrix.

$$FOOD(N,I,1) = FOOD(K,I,1) * (.42 * (DWF ** .5) + .58 * PPRG) \quad (5)$$

where

FOOD(N,I,1) = detritus (food 1) for the Ith period of the Nth year; BOD, lb/day

FOOD(K,I,1) = same as above except K = N - 1;

DWF = ratio of total freshwater inflow, current (N) to prior (N-1) years;

PPGR = ratio of phytoplankton growth rates of prior (N - 1 year) to two years ago (N - 2 year).

Phytoplankton concentrations are a function of short term (seasonal) environmental parameters. Growth rates are based on data of Copeland and Fruh (1970) from which the following relation was obtained by a multiple-regression analysis:

$$PPG(N) = .8211 - .0207 * AANIT(N) - .0129 * AANIT(N)^2 + .0449 * AASAL(N) \quad (6)$$

where

PPG(N) - Phytoplankton growth multiplier in Nth year

AANIT(N) - Average annual total nitrogen in Nth year, mg/L

AASAL(N) - Average annual salinity in Nth year,ppt

Vascular plant material - due to the large quantities of submerged grasses in the Galveston Bay this material is always considered to be in excess.

Foods 4 through 8 are consumers in the Galveston Bay and current biomass levels are used in the iterative calculations. Food 4 quantity equals biomass for consumer group 1, food 5 for consumer group 2, etc. Only "young" consumer levels are used in determining the equivalent food densities.

Food density effects are determined from the investigation of Brocksen, Davis and Warren (1970) (see Figure 13) and are defined in the model as follows:

$$FF(J) = \frac{1 + .01 * (1.2*.75*A\ LOG\ 10(FOOD(N,IH,J)*FQ(J)))}{1 + .01*(1.2*.75*A\ LOG\ 10\ (FOOD(N-1),IH,J)*FQ(J)))} \qquad (7)$$

where

FF(J) - growth multipliers due to food J;

FOOD(N,IH,J) - Food quantity - Nth year, IH (= I - 1) period, Jth Food, BOD (lb/day) or grams;

FOOD(N-1,IH,J) - Same as above for prior year and

FQ(J) - equalizing factor for various food densities and types.

Specifically, constants FQ(J) in the expression are related to maximum food density of 400 mg/m^3; thus FQ(J) values are 400/(Max level of food J in baseline year) (Brocken, Davis and Warren, 1970).

C-2

The term FF(J) is then multiplied by the appropriate energy source matrix (ENERS) term and summed over J = 1,...8, for each consumer group. This food-effects factor is designated R(L) in the model.

Quantitative expression for consumer density is (Brocksen, Davis and Warren, 1970)

$$GRCONSD(L) = \frac{1 + .0275\ (1. - (CONSIL(L)/CONSTL(7)*\ 4.)}{1 + .0275\ (1. - .25)} \tag{8}$$

where

CONSIL(L) is the consumer biomass level at the beginning of the current period, grams

CONSTL(7) is the consumer biomass level for the same period in the base-line year (at biomass levels four times those of the baseline year, growth rates are taken as zero; Brocksen, Davis and Warren, 1970), grams.

Calculation procedure is to use food and consumer densities from the previous period along with the energy source matrix for the current period (note that food densities at the end of this previous period are the same as the values at the start of the current period).

To allow for the omnivarious feeding of estuarine species (Darnell, 1958), if the food - consumer density parameter is less than 1, the calculated value is raised to the .8 power (i.e., hungry organisms make

more effort and/or are less food selective); no quantitative work is reported; however, the model is not sensitive to this value

The food-consumer density parameter (product of R(L) and GRCONSD(L)) is raised to the 14th power, which is the number of days in a model period. This term is designated GEPYR(I,L,2) (or GEPAR for adult biomass) and is the growth ratio compared to the prior year.

Growth change for the six consumers groups due to environmental parameters changes is

$$GEPYR(I,L,3) = FG(N)/FG(N - 1) \quad (9)$$

where

GEPYR(I,L,3) - growth ratio of current to prior year due to environmental parameters change (young organisms);

FG(N) - fish growth multiplier in current year (FG(N) = 1.1 - .1 *(10) AANIT(N)/AANIT(1); where AANIT is average annual total nitrogen);and

FG(N-1) - fish growth in prior year.

Growth rate effects due to changes in distribution of organisms in the estuary as a result of changes in environmental parameters and their relation to geophysical (and consequent water and waste distribution) factors is important in the life and growth of estuarine organisms (Copeland 1966, Armstrong and Hinson 1973). Temperatures and other

factors are apparently of secondary importance relative to salinity and pollution effects in this ecosystem in successive years. In the model, a quantitative relation is based on the concept that when freshwater input decreases shrimp and crabs (consumer group 3) have less area in which to spawn and grow with minimum predator effects; while zooplankton and primary and secondary canivores have greater feeding area and a predator advantage due to greater penetration into the marshes. Empirical equations are developed from data and analyses of Copeland (1966) and Armstrong and Hinson (1973).

For omnivores (consumer group 3, shrimp and crabs)

GEPAR(I,3,4) = (1. +(.54*((OMNG(N)/OMNG(N-1))-1.)))**(1./26.) (11)

where

GEPAR(I,3,4) a growth rate ratio in period I for consumer group 3 due to growth changes of this consumer group due to distribution factors (sequential number 4);

OMNG(N) = omnivore (consumer group 3) growth rate for the current year and is determined by OMNG(N) = 0.09467*(25.-AASAL(N-2))**2.05 (see Figure 16); and OMNG(N-1) is same as above for prior year.

Galveston Bay total productivity (biomass) is dominated by the consumer groups 4 (primary carnivores) and 5 (middle carnivores). Zooplankton and herbivore growth rates would be increased as a result of increased salinities (Cooper, 1967). Growth rate ratio equations are

$$GEPYR(I,1,4) = .50 + .50*AASAL(N)/AASAL(1) \tag{12}$$

where

GEPYR(I,1,4) = growth rate multiplier in the $I^{\underline{th}}$ period for the first consumer group due to distribution effects (4) and

AASAL(N) - average annual salinity, current year

(Note that average annual salinity for baseline year is AASAL(1).)

GEPAR(I,1,4), adults of zooplankton; GEPYR(i,4,4), GEPAR(I,4,4), young and adults of primary carnivores; and GEPYR(I,5,4), GEPAR(I,5,4) young and adults of middle carnivores are determined in the same manner. Application of the above empirical equations are shown in the calibration curve, Figure 17.

A net growth rate is determined from the product of the prior year growth rate and change ratios due to

(a) food and consumer densities;

(b) environmental parameters and

(c) distribution

This product is determined and applied iteratively period by period in the model to obtain new biomass levels for the six consumer groups.

Adult biomass levels for each consumer group are based on the same factors as for young, except using energy source matrices and food curves for this particular class. In the baseline year, it is assumed that; due to mortality, exchange through the passes connecting the Galveston Bay to the Gulf of Mexico and other factors, the net growth

rate is a constant value, equal to 0. (i.e., multiplying factor = 1.0).

In subsequent years, emigration of adult biomass out of the estuary is assumed to increase in direct proportion to the ratio of net growth rates of the current to previous years (i.e., if too competive for food, adults leave). Biomass growth greater than the change in the ecosystem emigrates and is included in the total emigration.

In the model, adult biomass change in a period is determined by:

PERGRA(I,L) = ABGROW * (GEPAR(I,L,5) - 1.0) (13)

where

PERGRA(I,L) = adult biomass change in period I for consumer group L grams;

ABGROW = adult biomass at beginning of period I for consumer group L grams; and

GEPAR(I,L,5) = net growth rate multiplier

Adult biomass at the end of the period is

ACONSIL(L) = ABGROW * GEPAR(I,L,5)/FEPAR(I,L,5) (14)

where

ACONSIL(L) = adult biomass grams at the end of period I; and

FEPAR(I,L,5) = net growth rate multiplier for prior year.

Adult biomass emigrating during the period is

PERAFM(I,L) = PERGRA(I,L) - (ACONSIL(L) - ABGROW)

This latter value is added to the "young" biomass emigration to obtain the total emigration for the period.

APPENDIX B

A computer program print-out, including input data and coefficients, is listed for the case of increased freshwater inflow to the Galveston Bay. Results are listed in Table II and plotted in figures 18 through 24.

```
      DIMENSION EXRGR(26,6),SUMEXGR(6)   ,RN(26,6)
      DIMENSION EM1(6,3),EM2(6,2),IEM(6,2),S(26,6),FOODI(26,8)
      DIMENSION YRESU(26)
      DIMENSION                FAVRT(26,6),CONS4L(26,6),CONS5L(26,6),CONS6
     1L(26,6),GRCO(20,26,6)   ,FOOD(20,26,8)
      DIMENSION WATERSU(20,4),WASTESU(20,4),RWT(20,4),RRWT(20,4),RWS(20,
     14),RRWS(20,4),WPARAM(7,27)
      DIMENSION ENERS(26,8,6),SECONS(26,6)  ,R6(6),FD(8)
      DIMENSION WSDISU(20),WTDISU(20),WSDI(27),WTDI(27)
      DIMENSION          IN(2),YCONS(520),XP(520),YCONSI(520,6)
      DIMENSION OMNG(20)  ,ZP(26)
      DIMENSION I1(6),I2(6),I3(6),I4(6),I5(6),I6(6),R1(6),R2(6),R3(6),R4
     1(6),R5(6),ACONS1L(6),YCONS1L(6),CONS1L(6),CONS1L(26,6),CONS2L(26,6
     2),CONS3L(26,6),CONSIM(26,6),CONSEM(26,6),FOREM(26,6),TCONSIM(6),TC
     3ONSEM(6),CONSTIM(6),FACTEM(6),SAMP(26,6),GEPAR(26,6,5),GEPYR(26,6,
     45),BLYGR(6),RCALSAM(26,6),CORR(6),FAV(8),FF(8),AP(6),AM(6)
     5,FEPYR(26,6,5),FEPAR(26,6,5),PPG(20),FG(20),TFWD(20),TWD(20),AASAL
     5(20)
     6,AANIT(20),ACONSEM(6),RESULT(20,6,20),DATA(20,10),PERGRA(26,8),
     7PERGRY(26,6),TAFCONS(8),AVGFOOD(8),TPFCONS(26,8),PFCONS(26,8,6),
     8RFCA(8),ACONSOM(6)
      DIMENSION CONS7L(20,26,6),PERAEM(26,6)  ,YM(2)
      CALL PSEUDO
      IN(1)=10H1232   RWJH
      IN(2)=10HR205   SATD
      NP=0
      XM=10HYEAR
      PFAF=0.05
      PFYF=0.05
      READ (5,10) (FOOD(1,I,1),I=1,26)
   10 FORMAT (8F10.0)
      DO 252 I=1,26
      FOOD(1,I,1)=FOOD(1,I,1)-550.
      READ(5,253)FOOD(1,I,2)
  253 FORMAT(F10.0)
      FOOD(I,I,3)=1.
  252 CONTINUE
C READ IN SAMPLED VALUES
C SAMPLED VALUES IN GALV BAY S(I,L)
      DO 58 I=1,26
      READ(5,59)S(I,1),S(I,2),S(I,3),S(I,4),S(I,5),S(I,6)
```

```
 59 FORMAT(6F10.0)
    S(I,6)=S(I,6)/10.
    IF(I.GT.1)GO TO 60
    WRITE(6,61)
 61 FORMAT(6X5HSAMP15X5HSAMP25X5HSAMP35X5HSAMP45X5HSAMP55X5HSAMP6)
 60 CONTINUE
    WRITE(6,62)        S(I,1),S(I,2),S(I,3),S(I,4),S(I,5),S(I,6)
 62 FORMAT(1X,6F10.0)
 58 CONTINUE
C ENERS(M,J,L) M PERIOD AFTER IM,J FOOD,L CONSUMER
    DO 57 M=1,26
    DO 57 J=1,8
    DO 57 L=1,6
    ENERS(M,J,L)=0.
 57 CONTINUE
    DO 240 M=1,26
    RM=FLOAT(M)
    ENERS(M,1,1)=.1
    ENERS(M,2,1)=.9
    RMA=(RM-6.)/20.
    RMB=(RM-6.)/7.
    RMC=(RM-13.)/13.
    RMD=(RM-13.)/7.
    IF(RMA.LT.0.)RMA=0.
    IF(RMB.LT.0.)RMB=0.
    IF(RMC.LT.0.)RMC=0.
    IF(RMD.LT.0.)RMD=0.
    IF(RMA.GT.1.)RMA=1.
    IF(RMB.GT.1.)RMB=1.
    IF(RMC.GT.1.)RMC=1.
    IF(RMD.GT.1.)RMD=1.
    ENERS(M,1,2)=.5+RMA*.3
    ENERS(M,2,2)=.4-RMA*.2
    ENERS(M,4,2)=.1-RMA*.1
    ENERS(M,1,3)=.2+RMB*.3
    ENERS(M,2,3)=.6-RMB*.5
    ENERS(M,4,3)=.1
    ENERS(M,5,3)=.1+RMB*.2
    ENERS(M,1,4)=.2+RMB*.3-RMC*.4
    ENERS(M,3,4)=.1
    ENERS(M,4,4)=.6-RMB*.5-RMC*.1
    ENERS(M,5,4)=.1+RMB*.05+RMC*.25
    ENERS(M,5,4)=.1+RMB*.05+RMC*.25
```

```
      ENERS(M,1,5)=.5-RMB*.3
      ENERS(M,4,5)=.5-RMB*.25
      ENERS(M,5,5)=RMB*.5
      ENERS(M,6,5)=RMB*.05
      ENERS(M,4,6)=.3-RMB*.3+RMD*.1
      ENERS(M,5,6)=.3+RMB*.1-RMD*.35
      ENERS(M,6,6)=.3+RMB*.3-RMD*.55
      ENERS(M,7,6)=.1+RMD*.1
      ENERS(M,8,6)=RMD*.6
  240 CONTINUE
C NORMALIZE ENERS REQT FOR EACH CONSUMER LEVEL
      DO 241 M=1,26
      DO 241 L=1,6
      SECONS(M,L)=0.
      DO 241 J=1,8
      SECONS(M,L)=SECONS(M,L)+ENERS(M,J,L)
  241 CONTINUE
      DO 242 M=1,26
      DO 242 L=1,6
      DO 242 J=1,8
      ENERS(M,J,L)=ENERS(M,J,L)/SECONS(M,L)
  242 CONTINUE
      DO 213 L=1,6
      I6(L)=0
  213 CONTINUE
C READ IN IM AND FM FACTORS,RL,Y AND A GROWTH RATES
      DO 221 L=1,6
      READ(5,220) I1(L),I2(L),I3(L),I4(L),I5(L),CONSTIM(L),FACTEM(L),RLY
     1GR(L)
  220 FORMAT(5I6,F10.1,2F10.5)
      IF(L.GT.1) GO TO 223
      WRITE(6,222)
  222 FORMAT(4X2HI14X2HI24X2HI34X2HI44X2HI53X7HCONSTIM4X6HFACTEM5X5HRLYG
     1R)
  223 CONTINUE
      WRITE(6,224)I1(L),I2(L),I3(L),I4(L),I5(L),CONSTIM(L),FACTEM(L),RLY
     1GR(L)
  224 FORMAT(5I5,F10.1,2F10.5)
  221 CONTINUE
      DO 225 I=1,26
      DO 225 L=1,6
      DO 225 M=1,5
```

```
      GEPAR(I,L,M)=1.0
      GEPYR(I,L,M)=1.0
      FEPAR(I,L,M)=1.0
      FEPYR(I,L,M)=1.0
  225 CONTINUE
C EXP GROWTH FACTOR FOR YOUNG,1.0 FOR ADULT FOR BASELINE YEAR
      DO 286 L=1,6
      SUMEXGR(L)=0.0
      DO 229 I=1,26
      EXPGR(I,L)=          (EXP(.05*(27-I) )-1. )
      SUMEXGR(L)=SUMEXGR(L)+EXPGR(I,L)
  229 CONTINUE
      DO 230 I=1,26
      FEPYR(I,L,1)=              EXPGR(I,L)/SUMEXGR(L)
  230 CONTINUE
      CORR(L)=BLYGR(L)/(FEPYR(13,L,1)+1.0)
      CORR(L)=(BLYGR(L)-1.)/FEPYR(13,L,1)
      DO 286 I=1,26
      FEPYR(I,L,1)=FEPYR(I,L,1)*CORR(L)+1.0
      FEPYR(I,L,1)=1.0
      FEPAR(I,L,1)=1.0
  286 CONTINUE
  235 CONTINUE
      N=1
      N1=1
      N2=6
  290 CONTINUE
C DETERMINE AASAL $ AANIT ON STATION BY STATION BASIS
C WPARAM-WATER PARAMETERS-STATION,FRACTIONS BOLIVAR ROADS,TRINITY RIVER,
C HSC,OTHER,SALINITY(PPT),TOTAL NITROGEN(MG/L)
      AASAL(N)=0.
      AANIT(N)=0.
      IF(N.GT.1) GO TO 5118
C DETERMINE AASAL $ AANIT FROM CHANGE IN FRESHWATER $ WASTE DISCHARGES
      DO 5115 I=1,27
      READ(5,5116)(WPARAM(J,I),J=1,7)
 5116 FORMAT(7F10.2)
      IF(I.GT.1) GO TO 5127
      WRITE(6,5126)
 5126 FORMAT(3X7HSTATION3X7HFRACTBR3X7HFRACTTR2X8HFRACTHSC5X5HOTHER7X4H
     1SAL5X5HT NIT/)
 5127 CONTINUE
      WRITE(6,5116)(WPARAM(J,I),J=1,7)
```

```
      AASAL(N)=AASAL(N)+WPARAM(6,I)/27.
      AANIT(N)=AANIT(N)+WPARAM(7,I)/27.
 5115 CONTINUE
      NYEAR=N
 6050 CONTINUE
C WATER & WASTE SOURCES-TRINITY RIVER,HSC,OTHER,TOTAL-WATER CFS,WASTE 10E06
C POUNDS BODS PER YEAR
      READ(5,5120)(WATERSO(N,K),K=1,4),(WASTESO(N,L),L=1,4)
 5120 FORMAT(8F10.2)
      IF(WATERSO(N,1).EQ.0.) GO TO 5119
      IF(N.GT.1)GO TO 5128
      WRITE(6,5129)
 5129 FORMAT(1X19HWATER DISCHARGE,CFS20X29HWASTE DISCHARGE MILLIONS POUN
     1DS BOD)
      WRITE(6,5130)
 5130 FORMAT(3X7HT RIVER7X3HHSC5X5HOTHER5X5HTOTAL3X7HT RIVER7X3HHSC5X
     15HOTHER5X5HTOTAL)
 5128 CONTINUE
      DO 7003 NM=1,4
      WASTESO(N,NM)=WASTESO(1,NM)
      IF(N.EQ.1) GO TO 7003
      IF(N.GT.5) GO TO 7004
      WATERSO(N,NM)=WATERSO(1,NM)/1.21
      GO TO 7003
 7004 CONTINUE
      WATERSO(N,NM)=1.1*WATERSO(N-1,NM)
 7003 CONTINUE
      WRITE(6,5120)(WATERSO(N,K),K=1,4),(WASTESO(N,L),L=1,4)
      DO 5139 K=1,4
      RWT(1,K)=1.
      RWS(1,K)=1.
      IF(N.EQ.1) GO TO 5139
      RWT(N,K)=WATERSO(N,K)/WATERSO(N-1,K)
      RWS(N,K)=WASTESO(N,K)/WASTESO(N-1,K)
 5139 CONTINUE
      N=N+1
      GO TO 6050
 5119 CONTINUE
      N=N-1
      NNN=N
      N=NYEAR
 5118 CONTINUE
      WTOISO(N)=0.
```

```
      WSDISU(N)=0.
      DO 5121 I=1,27
      WSDI(I)=            (WPARAM(2,I)+WPARAM(3,I)*RWS(N,1)+WPARAM(4,I)
     1*RWS(N,2)+WPARAM(5,I)*RWS(N,3))
      WTDI(I)=            (WPARAM(2,I)+WPARAM(3,I)*RWT(N,1)+WPARAM(4,I)
     1*RWT(N,2)+WPARAM(5,I)*RWT(N,3))
      WSDISU(N)=WSDISU(N)+WSDI(I)/27.
      WTDISU(N)=WTDISU(N)+WTDI(I)/27.
      DO 5141 M=2,5
      IF(M.NE.2) GO TO 5122
      WPARAM(M,I)=WPARAM(M,I)/WTDI(I)
      GO TO 5141
 5122 CONTINUE
      WPARAM(M,I)=WPARAM(M,I)*RWT(N,M-2)/WTDI(I)
 5141 CONTINUE
 5121 CONTINUE
      IF(N.EQ.1) GO TO 5117
      AANIT(N)=AANIT(N-1)*WSDISU(N)          /              WTDISU(N)
      XYZW=      WATERSO(1,4)*ALOG(AASAL(1)/32.)/ALOG(.5)
      AASAL(N)= 32.*(.5)**(WATERSO(N,4)/XYZW)
      AASAL(N)=32.*(AASAL(N-1)/32.)**WTDISU(N)
      WRITE(6,5301)AASAL(N),AASAL(N-1),WTDISU(N),
     1                                   AANIT(N),AANIT(N-1),WSDISU
     2(N),N
 5301 FORMAT(6E16.8,I3)
 5117 CONTINUE
 5125 CONTINUE
      DATA(N,1)=WATERSO(N,4)
      DATA(N,2)=WASTESO(N,4)
      DATA(N,3)=AASAL(N)
      DATA(N,4)=AANIT(N)
      FG(N)=1.1-.1*AANIT(N)/AANIT(1)
      PPG(N)=.8211-.0207*AANIT(N)-.0129*(AANIT(N)**2.)+.0449*AASAL(N)
      NK=N-2
      IF(NK.LT.1) NK=1
      OMNG(N)= .0946*(25.-AASAL(NK))**2.05
      DATA(N,5)=PPG(N)
      DATA(N,6)= FG(N)
C CALC DE(1) $ PP(2)
      IF(N.LE.1)GO TO 450
      IF(N.EQ.2) PPGR=PPG(N)/PPG(N-1)
      IF(N.GT.2) PPGR=PPG(N-1)/PPG(N-2)
  454 CONTINUE
```

```
      K=N-1
      DWF=RWT(N,4)
      DEF=RWS(N,4)
      DO 453 I=1,25
      FOOD(N,I,1)=FOOD(K,I,1)*(.42*(DWF**.50)+.58*PPGR)
      FOOD(N,I,2) =FOOD(K,I,2)*PPG(N)/PPG(N-1)
      FOOD(N,I,3) =FOOD(K,I,3)
  453 CONTINUE
  450 CONTINUE
      DO 200 NY=N1,N2
      DO 303 L=1,6
      TCONSIM(L)=0.
      TCONSEM(L)=0.
  303 CONTINUE
      DO 287 I=1,26
      DO 287 L=1,6
      FOREM(I,L)=0.
      CONSEM(I,L)=0.
      CONSIM(I,L)=0.
  287 CONTINUE
      DO 203 I=1,26
      DO 203 L=1,6
      IF(NY.GT.1) GO TO 207
      R1(L)=FLOAT(I-I1(L))
      R2(L)=FLOAT(I2(L)-I1(L))
      IF(R2(L).LT.0.)R2(L)=R2(L)+26.
      IF(R1(L).LT.0.)GO TO 203
      IF(R1(L).EQ.0.)GO TO 204
  207 CONTINUE
      I6(L)=I6(L)+1
      IF(I6(L).GT.26)I6(L)=1
      M=I6(L)
      KN(I,L)=M
C CORRELATE M AND I FOR EACH L
      GEPAR(I,L,1)=FEPAR(M,L,1)
      GEPYR(I,L,1)=FEPYR(M,L,1)
C CALC GROWTH RATE EFFECT DUE TO ENVIR % POLL
      IF( N.EQ.1)GO TO 288
C CALC GROWTH RATE FOR CURRENT YEAR
C CURRENT YEAR GROWTH RATE - FOOD AVAILABILITY AND CONSUMER DENSITY
      FAVRT(I,L)=0.
      IH=I-1
      IF(IH.LT.1)IH=1
```

```
      IJ=I6(L)-1
      IF(IJ.LT.1)IJ=1
      FQ(1)=400./836.
      FQ(2)=400./58.
      FQ(3)=400./1.
      FQ(4)=400./750000.
      FQ(5)=400./4375.
      FQ(6)=400./12425.
      FQ(7)=400./56689.
      FQ(8)=400./34307.
C DETERMINE GROWTH CHANGE DUE TO CONSUMER DENSITY
      GRCONSD=1.
      IF(I.EQ.1) GO TO 5101
      GRCO(1,I,L)=1.0
      GRCO(N,I,L)=
     1          (1.+.0275*(1.-CONSTL(L) /(CONS7L(1,IH,L)*4.)))/
     2          (1.+.0275*(1.-.25))
      GRCONSD=GRCO(N,I,L)/GRCO(N-1,I,L)
 5101 CONTINUE
      DO 256 J=1,8
      IF(J.LE.3) GO TO 5150
      IF(I.EQ.1) FOOD(N,IH,J)=FOOD(N-1,IH,J)
      IF(N.LE.2) GO TO 5150
      IF(I.EQ.1)FOOD(N,IH,J)=FOOD(N-1,26,J)
      IF(I.EQ.1)FOOD(N-1,IH,J)=FOOD(N-2,26,J)
 5150 CONTINUE
      FF(J)=0.
C     IF(ENERS(IJ,J,L).EQ.0.)GO TO 256
      FF(J)=(1.+.01*(1.2+.75*ALOG10(FOOD(N,IH,J)*FQ(J))))/
     1      (1.+.01*(1.2+.75*ALOG10(FOOD(N-1,IH,J)*FQ(J))))
      FAV(J)=ENERS(IJ,J,L)*FF(J)
      FAVRT(I,L)=FAVRT(I,L)+FAV(J)
  256 CONTINUE
C     WRITE(6,470)FQ(1),FQ(2),FQ(3),FQ(4),FQ(5),FQ(6),FQ(7),FQ(8),I,L,N
C     WRITE(6,470)FF(1),FF(2),FF(3),FF(4),FF(5),FF(6),FF(7),FF(8),I,L,N
  470 FORMAT(8F10.4,3I6)
      R=FAVRT(I,L)
C TO ALLOW FOR FOOD SUBSTITUTIONS
      IF(R.LT.1.)R=R**.8
      RR=R
C GROWTH RATES PER DAY,MODEL PERIOD 14 DAYS
      GEPYR(I,L,2)=(R*GRCONSD)**14.
      FAVRT(I,L)=0.
```

```
      DO 258 J=1,8
      FF(J)=0.
C     IF(ENERS(26,J,L).EQ.0.)GO TO 258
      FF(J)=(1.+.01*(1.2+.75*ALOG10(FOOD(N,IH,J)*FQ(J)))))/
     1       (1.+.01*(1.2+.75*ALOG10(FOOD(N-1,IH,J)*FQ(J)))))
      FAV(J)=ENERS(26,J,L)*FF(J)
      FAVRT(I,L)=FAVRT(I,L)+FAV(J)
  258 CONTINUE
      R=FAVRT(I,L)
C TO ALLOW FOR FOOD SUBSTITUTIONS
      IF(R.LT.1.)R=R**.8
C GROWTH RATES PER DAY,MODEL PERIOD 14 DAYS
      GEPAR(I,L,2)=(R*GRCONSD)**14.
C     WRITE(6,6000)GRCONSD,RR,GEPYR(I,L,2),R,GEPAR(I,L,2),I,L
 6000 FORMAT(5E16.8,2I6)
C     GEPAR(I,L,2)=(.3946*R-.1623*R**2.+. 0232*R**3.)/.2555
      GEPYR(I,L,3)=1.0
      GEPAR(I,L,3)=1.0
      GEPAR(I,L,3)=FG(N)/FG(N-1)
      GEPYR(I,L,3)=FG(N)/FG(N-1)
      GEPAR(I,L,4)=1.
      GEPYR(I,L,4)=1.
C CALC GROWTH RATE EFFECT DUE TO DISTRIBUTION
C WHEN FRESH WATER DECREASES SHRIMP AND CRABS HAVE LESS AREA
C  WHEN FRESH WATER INPUT DECREASES ZP PRIM AND  MID CARN HAVE GR AREA
      GEPAR(I,1,4)=  .500+ .500*AASAL(N)/AASAL(N-1)
      GEPYR(I,1,4)=GEPAR(I,1,4)
      GEPAR(I,3,4)= (1.+( .54 *((OMNG(N)/OMNG(N-1))-1.)))**(1./26.)
      GEPYR(I,3,4)=GEPAR(I,3,4)
      GEPAR(I,4,4)=GEPAR(I,1,4)
      GEPYR(I,4,4)=GEPAR(I,1,4)
      GEPAR(I,5,4)=GEPAR(I,1,4)
      GEPYR(I,5,4)=GEPAR(I,1,4)
  452 CONTINUE
  260 CONTINUE
C STORE PRIOR   YEAR NET GROWTH RATE
      FEPAR(I,L,5 )=GEPAR(I,L,5 )
      FEPYR(I,L,5 )=GEPYR(I,L,5 )
  288 CONTINUE
C DETERMINE CURRENT YEAR NET GROWTH RATE
  510 CONTINUE
      IF (N.EQ.1) FEPAR(I,L,5)=GEPAR(I,L,1)
      IF (N.EQ.1) FEPYR(I,L,5)=GEPYR(I,L,1)
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```
      GEPYR(I,L,5)=FEPYR(I,L,5)*GEPYR(I,L,2)*GEPYR(I,L,3)*GEPYR(I,L,4)
      GEPAR(I,L,5)=FEPAR(I,L,5)*GEPAR(I,L,2)*GEPAR(I,L,3)*GEPAR(I,L,4)
      R1(L)=FLOAT(I6(L)-1)
  208 CONTINUE
      RX12=R1(L)/R2(L)
      CONSIM(I,L)=0.0
      IF(RX12.GT.1.)GO TO 205
      CONSIM(I,L)=SIN(R1(L)*3.1416/R2(L))*CONSTIM(L)
  205 CONTINUE
      R3(L)=R1(L)-FLOAT(I3(L)-I1(L))
      IF(R3(L).GE.26.)R3(L)=R3(L)-26.
      IF(R3(L).LT.0.) GO TO 210
      R4(L)=FLOAT(I4(L)-I3(L))
      IF(R4(L).LE.0.)R4(L)=R4(L)+26.
      R5(L)=R1(L)-FLOAT(I5(L)-I1(L))
      IF(R5(L).GE.26.)R5(L)=R5(L)-26.
      IF(R5(L).LT.0.)GO TO 280
      R6(L)=FLOAT(I1(L)-1-I5(L))
      IF(R6(L).LE.0.) R6(L)=R6(L)+25.
      RX56=R5(L)/R6(L)
      IF(RX56.GT.1.) GO TO 280
  212 FOREM(I,L)=        YCONSIL(L)              *( R5(L)/(R6(L)+1.))
      IF(FOREM(I,L).LT.0.)FOREM(I,L)=0.
      GO TO 281
  280 FOREM(I,L)=0.
  281 CONTINUE
      RX34=R3(L)/R4(L)
      IF(RX34.GT.1.) GO TO 282
      CONSEM(I,L)=
     1           SIN(R3(L)*3.1416/R4(L))*FACTEM(L)*YCONSIL(L)+FOREM(I,L)
      GO TO 283
  282 CONSEM(I,L)=FOREM(I,L)
  283 CONTINUE
      GO TO 211
  210 CONSEM(I,L)=0.0
  211 CONTINUE
      ABGROW=ACONSIL(L)
      PERGRY(I,L)=YCONSIL(L)*(GEPYR(I,L,5)-1.)
      IF(PERGRY(I,L).LT.0.) PERGRY(I,L)=0.
      PERGRA(I,L)=ACONSIL(L)*(GEPAR(I,L,5)-1.)
      IF(M.EQ.1 )CONSEM(I,L)=YCONSIL(L)*GEPYR(I,L,5)
      ACONSIL(L)=ACONSIL(L)*GEPAR(I,L,5)/FEPAR(I,L,5)
      IF(M.EQ.1)ACONSEM(L)=ACONSOM(L)
```

```
      RESULT(N,L,3)=ACONSEM(L)
      YCONSIL(L)=YCONSIL(L)*GEPYR(I,L,5)+CONSIM(I,L)-CONSEM(I,L)
      IF(M.EQ.I)ACONSOM(  L)=0.
C ADULT EM=GROWTH-CHANGE IN BIOMASS IN SYSTEM
      PERAEM(I,L)=                PERGRA(I,L)-(ACONSIL(L)-ABGROW)
      ACONSOM(L)=ACONSOM(L)+ PERAEM(I,L)
      CONSEM(I,L)=CONSEM(I,L)+PERAEM(I,L)
      GO TO 202
  204 ACONSIL(L)=S    (I,L)
      YCONSIL(L)=0.
      CONSIM(I,L)=0.
      CONSEM(I,L)=0.
      I6(L)=1
  202 CONTINUE
      CONSIL(L)=ACONSIL(L)+YCONSIL(L)
      CONSIL(I,L)=ACONSIL(L)
      IF(YCONSIL(L).LE.1.) YCONSIL(L)=1.
      CONS2L(I,L)=YCONSIL(L)
      CONS3L(I,L)=CONSIL(L)
C STORE CONSUMER BIOMASS LEVELS BY YEAR
      CONS7L(N,I,L)=CONSIL(L)
      RCALSAM(I,L)=CONS3L(I,L)/S    (I,L)
C RCALSAM BASED ON YOUNG BIOMASS
C     XYZ=S(I,L)-CONSIL(I,L)
C     IF(XYZ.LT.1.)XYZ=1.
C     RCALSAM(I,L)=CONS2L(I,L)/XYZ
      IF(N.GT.1)RCALSAM(I,L)=CONS3L(I,L)/CONS6L(I,L)
      IF(L.GT.5) GO TO 254
      LL=L+3
      FOOD(N,I,LL)=CONS3L(I,L)
  254 CONTINUE
      TCONSIM(L)=TCONSIM(L)+CONSIM(I,L)
      TCONSEM(L)=TCONSEM(L)+CONSEM(I,L)
      RESULT(N,L,1)=TCONSIM(L)
      RESULT(N,L,2)=TCONSEM(L)
      REMIM=TCONSEM(L)/TCONSIM(L)
      RESULT(N,L,4)=REMIM
  203 CONTINUE
      IF(NY.LT.N2) GO TO 200
      DO 298 I=1,26
      NP=NP+1
      XP(NP)=FLOAT(NP)/26.
      DO 6100 L=1,6
```

```
      YCONSI(NP,L)=CONS3L(I,L)
 6100 CONTINUE
      IF(I.GT.1) GO TO 268
      WRITE(6,269)
  269 FORMAT(6X5HFOOD15X5HFOOD25X5HFOOD35X5HFOOD45X5HFOOD55X5HFOOD65X5HF
     1OOD75X5HFOOD85X1HI)
  268 WRITE(6,270)FOOD(N,I,1),FOOD(N,I,2),FOOD(N,I,3),FOOD(N,I,4),FOOD(N
     1,I,5),FOOD(N,I,6),FOOD(N,I,7),FOOD(N,I,8),I
  270 FORMAT(1X,8F10.1,I6)
  298 CONTINUE
      DO 5110 L=1,6
C SKIP DETAILED PRINTOUTS-5100
      GO TO 5100
      WRITE(6,219)
  219 FORMAT(4X7HTCONSIM3X7HTCONSEM4X2HNY5X1HL5X5HREMIM3X7HACONSEM)
      WRITE (6,218) TCONSIM(L),TCONSEM(L),NY,L,REMIM,ACONSEM(L)
  218 FORMAT (1X,2F10.1,2I6,F10.4,F10.1/)
      DO 310 I=1,26
      IF(I.GT.1) GO TO 311
      WRITE(6,300)
  300 FORMAT(5X6HGEPYR14X6HGEPYR24X6HGEPYR34X6HGEPYE44X6HGEPYR55X1HL)
  311 CONTINUE
      WRITE(6,301)GEPYR(I,L,1),GEPYR(I,L,2),GEPYR(I,L,3),GEPYR(I,L,4),
     1GEPYR(I,L,5),L
  301 FORMAT(1X,5F10.4,I6)
  310 CONTINUE
      DO 312 I=1,26
      IF(I.GT.1) GO TO 313
      WRITE(6,302)
  302 FORMAT(5X6HGEPAR14X6HGEPAR24X6HGEPAR34X6HGEPAE44X6HGEPAR55X1HL)
  313 CONTINUE
      WRITE(6,301)GEPAR(I,L,1),GEPAR(I,L,2),GEPAR(I,L,3),GEPAR(I,L,4),
     1GEPAR(I,L,5),L
  312 CONTINUE
      DO 216 I=1,26
      IF(I.GT.1) GO TO 215
      WRITE (6,214)
  214 FORMAT(4X7HACONSIL3X7HYCONSIL3X7HTCONSIL3X7HRCY/PRY4X6HCONSIM4X6HC
     1ONSEM4X2HNY5X1HI5X1HL5X1HM5X5HFOREM4X6HGEPYR54X6HGEPAR5)
  215 CONTINUE
      WRITE(6,217)CONS1L(I,L),CONS2L(I,L),CONS3L(I,L),RCALSAM(I,L),CONSI
     1M(I,L),CONSEM(I,L),NY,I,L ,KN(I,L),FOREM(I,L),GEPYR(I,L,5),GEPAR(I
```

```
     2,L,5)
  217 FORMAT(1X,6F10.2,4I6,F10.2,2F10.4)
  216 CONTINUE
 5100 CONTINUE
 5110 CONTINUE
C DETERMINE FOOD COSUMPTION BY TYPE,CONV EFF=.1
      DO 500 J=1,8
      TAFCONS(J)=0.
      AVGFOOD(J)=0.
      DO 500 I=1,26
      TPFCONS(I,J)=0.
  500 CONTINUE
      DO 504 J=1,8
      DO 501 I=1,26
      DO 503 L=1,6
      PFCONS(I,J,L)=(PERGRY(I,L)*ENERS(I,J,L)+PERGRA(I,L)*ENERS(26,J,L))
     1/.1
      TPFCONS(I,J)=TPFCONS(I,J)+PFCONS(I,J,L)
  503 CONTINUE
      TAFCONS(J)=TAFCONS(J)+TPFCONS(I,J)
      AVGFOOD(J)=AVGFOOD(J)+FOOD(N,I,J)/26.
  501 CO NTINUE
      RFCA(J)=TAFCONS(J)/AVGFOOD(J)
  504 CONTINUE
      WRITE(6,505)
  505 FORMAT(3X8HRFCO/AV12X8HFFCO/AV22X8HRFCO/AV32X8HFFCO/AV42X8HRFCO/AV
     152X8HRFCO/AV62X8HRFCO/AV72X8HRFCO/AV85X1HN)
      WRITE(6,506)RFCA(1),RFCA(2),RFCA(3),RFCA(4),RFCA(5),RFCA(6),RFCA(7
     1),RFCA(8),N
  506 FORMAT(1X,8E10.2,I6)
  200 CONTINUE
C STORE PR YEAR FOOD AND BIOMASS LEVELS
      DO 263 I=1,26
      DO 265 L=1,6
      CONS4L(I,L)=CONS1L(I,L)
      CONS5L(I,L)=CONS2L(I,L)
      CONS6L(I,L)=CONS3L(I,L)
  265 CONTINUE
  263 CONTINUE
C SUM TOTAL BIOMASS EM FOR YEAR
      RESULT(N,6,5)=0.
      DO 490 L=2,6
      RESULT(N,6,5)=RESULT(N,6,5)+RESULT(N,L,2)
```

```
490 CONTINUE
    N=N+1
    N1=N
    N2=N1
    IF(N.GT.NNN) GO TO 476
    GO TO 290
476 CONTINUE
    N=N-1
    DO 480 L=1,6
    DO 484 K=1,N
    IF(K.GT.1)GO TO 482
    WRITE(6,481)
481 FORMAT(7X4HAFWD7X3HAWD5X5HAASAL5X5HAANIT7X3HTIM7X3HTEM3X7HACONSEMS
   1X5HREMIN5X1HN5X1HL7X3HPPG8X2HFG5X5HTEMYR)
482 CONTINUE
    WRITE(6,483)DATA(K,1),DATA(K,2),DATA(K,3),DATA(K,4),RESULT(K,L,1),
   1RESULT(K,L,2),RESULT(K,L,3),RESULT(K,L,4),K,L ,DATA(K,5),DATA(K,6)
   2,RESULT(K,6,5)
483 FORMAT(1X,4E10.2,3E10.2,E10.2,2I5,3E10.2)
484 CONTINUE
    DO 485 NX=1,NP
    YCONS(NX)=YCONSI(NX,L)
485 CONTINUE
    IF(L.EQ.1)YM=13HZOOPLANKTON
    IF(L.EQ.2)YM=13HHERBIVORE
    IF(L.EQ.3)YM=13HOMNIVORE
    IF(L.EQ.4)YM=13HPRIM CARNIV
    IF(L.EQ.5)YM=13HMID CARNIV
    IF(L.EQ.6)YM=13HTOP CARNIV
    CALL DDIPLT(1,IN,NP,XP,YCONS,0.,0.,0.,0., 1,XM, 2,YM,11)
480 CONTINUE
    XM=10HYEAR
    YM=13HBIOMASS
    DO 7001 KL=1,9
    DO 7000 K=1,N
    ZP(K)=FLOAT(K)
    IF(KL.EQ.1) YRESU(K)=DATA(K,3)/10.
    IF(KL.EQ.2) YRESU(K)=DATA(K,4)
    IF(KL.EQ.3) YRESU(K)=       RESULT(K,1,2)/RESULT(1,1,2)
    IF(KL.EQ.4) YRESU(K)=       RESULT(K,2,2)/RESULT(1,2,2)
    IF(KL.EQ.5) YRESU(K)=       RESULT(K,3,2)/RESULT(1,3,2)
    IF(KL.EQ.6) YRESU(K)=       RESULT(K,4,2)/RESULT(1,4,2)
    IF(KL.EQ.7) YRESU(K)=       RESULT(K,5,2)/RESULT(1,5,2)
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```
      IF(KL.EQ.8) YRESU(K)=        RESULT(K,6,2)/RESULT(1,6,2)
      IF(KL.EQ.9) YRESU(K)=        RESULT(K,6,5)/RESULT(1,6,5)
 7000 CONTINUE
      IEC=0
      IF(KL.EQ.9) IEC=1
      ISYM=KL
      CALL DDIPLT(IEC,IN,N,ZP,YRESU,0.,0.,0.,2.0,1,XM,2,YM,ISYM)
 7001 CONTINUE
      XM=10HPERIOD
      YM=10HFRACT FOOD
      DO 7012 L=1,6
      DO 7013 J=1,8
      DO 7014 M=1,26
      YRESU(M)=ENERS(M,J,L)
      ZP(M)=FLOAT(M)
 7014 CONTINUE
      M=26
      IEC=0
      IF(J.EQ.8)IEC=1
      ISYM=J
      CALL DDIPLT(IEC,IN,M,ZP,YRESU,0.,0.,0.,1.0,1,XM,2,YM,ISYM)
 7013 CONTINUE
 7012 CONTINUE
      YM=13HBOD,LB/DAY
      DO 7020 M=1,26
      YRESU(M)=FOOD(1,M,1)
 7020 CONTINUE
      M=26
      IEC=1
      ISYM=1
      CALL DDIPLT(IEC,IN,M,ZP,YRESU,0.,0.,0.,0.,1,XM,2,YM,ISYM)
      YM=13HBIOMASS
      DO 7021 L=1,6
      DO 7022 M=1,26
      YRESU(M)=ALOG10(S(M,L))
 7022 CONTINUE
      M=26
      IEC=0
      IF(L.EQ.6) IEC=1
      ISYM=L
      AI=6.
      CALL DDIPLT(IEC,IN,M,ZP,YRESU,0.,0.,0.,AI,1,XM,2,YM,ISYM)
 7021 CONTINUE
```

```
      IEC=1
      ISYM=1
      DO 7023 M=1,26
      YRESU(M)=FOOD(1,M,7)
 7023 CONTINUE
      M=26
      CALL DDIPLT(IEC,IN,M,ZP,YRESU,0.,0.,0.,0.,1,XM,2,YM,ISYM)
      STOP
      END
```

SOURCE WATER FRACTIONS FOR GALV BAY STATIONS(COPELAND AND FRUH,1970)

STATION	FRACTBR	FRACTTR	FRACTHSC	OTHER	SAL	T NIT
1.	.74	.07	.14	.05	27.	0.
2.	.50	.0	.10	.40	25.22	.75
3.	.50	.0	.50	.0	22.8	.60
4.	.40	.10	.50	.0	17.	1.
5.	.25	.10	.65	.0	15.5	1.2
12.	.70	.0	.0	.30	22.5	.8
13.	.80	.0	.0	.20	29.	.4
14.	.75	.0	.0	.25	24.	.6
15.	.47	.16	.33	.04	19.	.92
16.	.49	.09	.18	.24	21.3	.82
17.	.50	.09	.18	.23	19.5	1.05
18.	.43	.16	.37	.04	13.5	.89
19.	.28	.16	.55	.01	11.5	1.15
20.	.24	.14	.61	.05	11.5	1.70
21.	.13	.09	.78		14.0	3.0
22.	.26	.15	.58	.01	14.8	1.81
23.	.24	.42	.36	.0	12.8	1.90
24.	.20	.54	.28	.0	4.5	1.00
25.	.16	.63	.22	.0	2.5	1.00
26.	.21	.52	.29	.0	7.4	.70
27.	.23	.48	.31	.0	7.	.9
28.	.31	.34	.37	.0	9.	.95
29.	.37	.27	.37	.0	11.	.90
30.	.35	.27	.38	.0	11.	.8
31.	.51	.09	.17	.23	22.5	.70
32.	.49	.09	.17	.25	21.	.70
36.	.14	.0	.86	.0	13.	5.